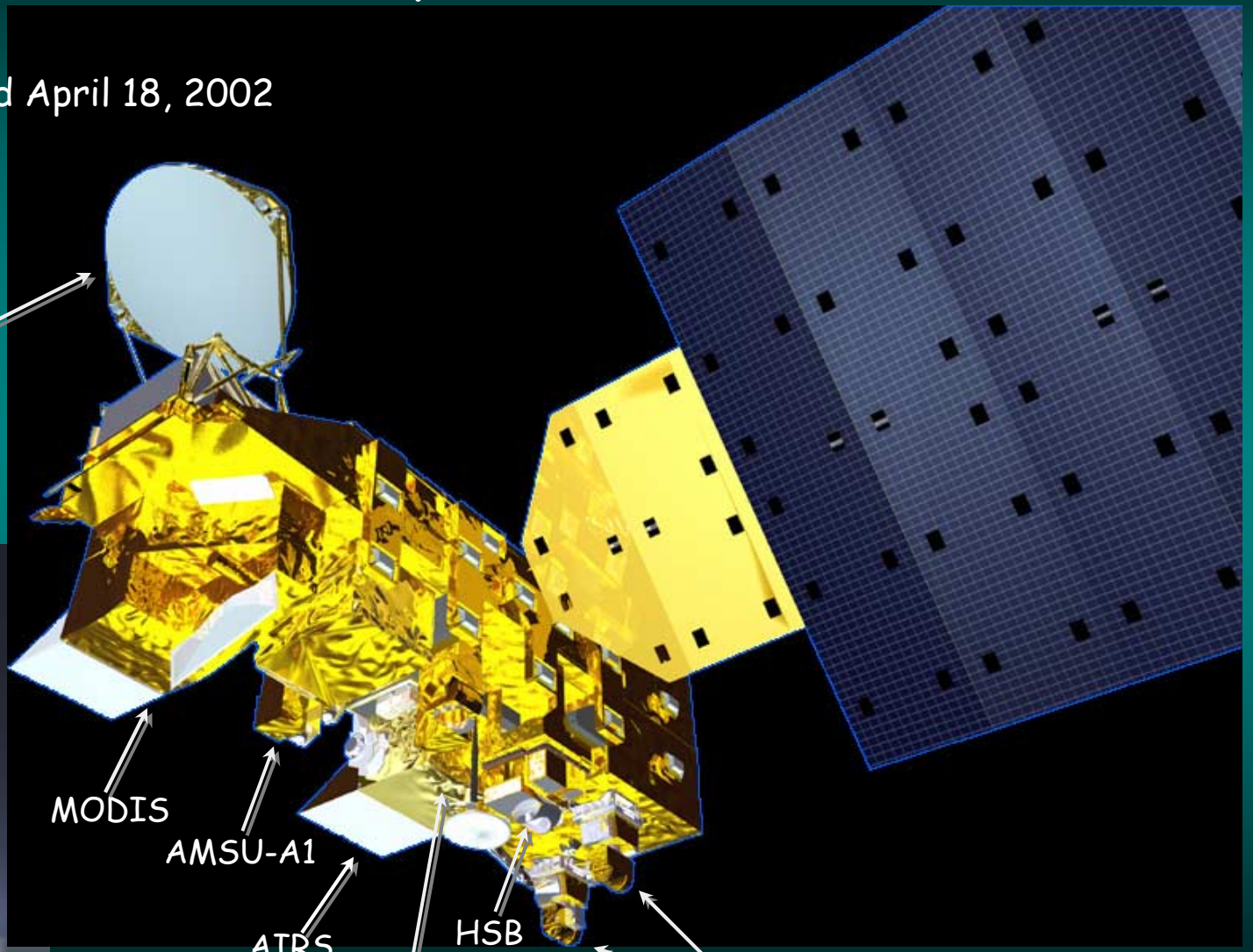
Validation of Remotely Sensed Cirrus Properties: The Role of Satellites and Aircraft

Michael D. King
NASA Goddard Space Flight Center

- Aqua
  - Remote sensing of the global water cycle
  - Orbit, sensors, and sampling characteristics
- Validation
  - Intercomparison of spaceborne and airborne sensors
  - Intercomparison of spaceborne and surface instrumentation

Aqua

Launch Scheduled April 18, 2002



Aqua's Orbit

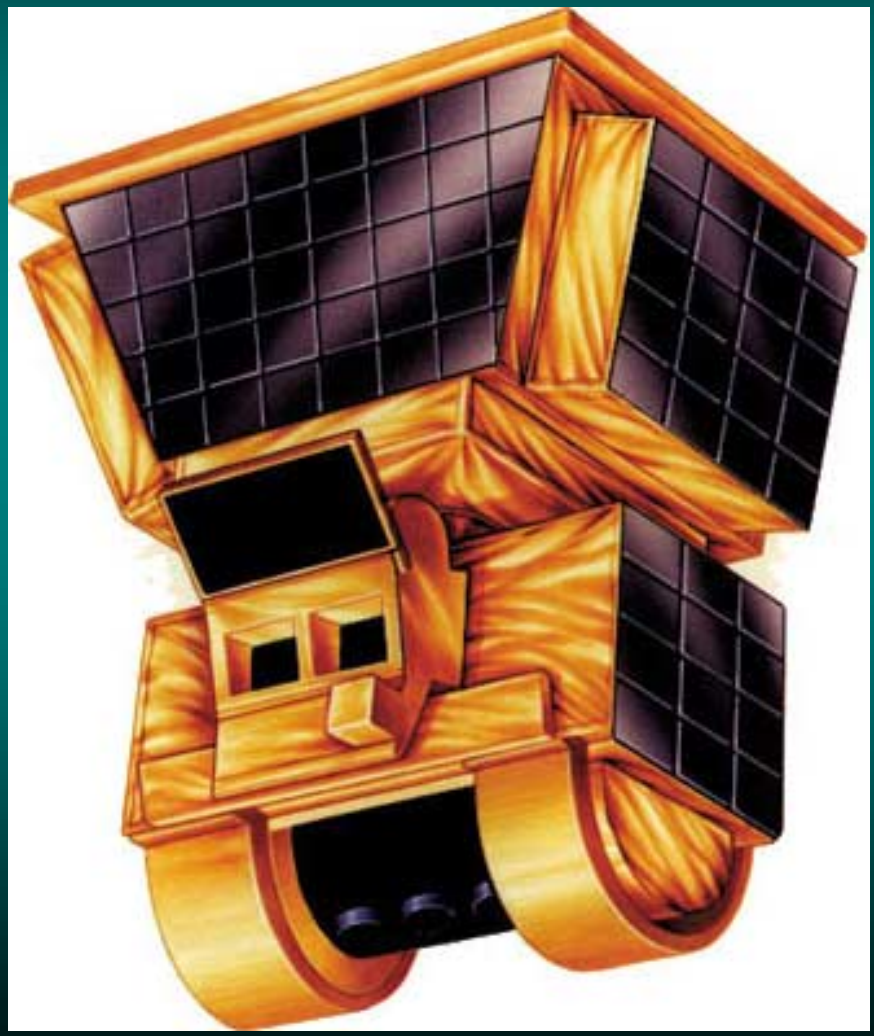
- Altitude of 705 km
- Near-polar, sun-synchronous, orbiting the Earth every 98.8 minutes, crossing the equator going north at 1:30 p.m. and going south at 1:30 a.m.

CERES Scan

QuickTime™ and a
Sorenson Video decompressor
are needed to see this picture.

Clouds and the Earth's Radiant Energy System (CERES)

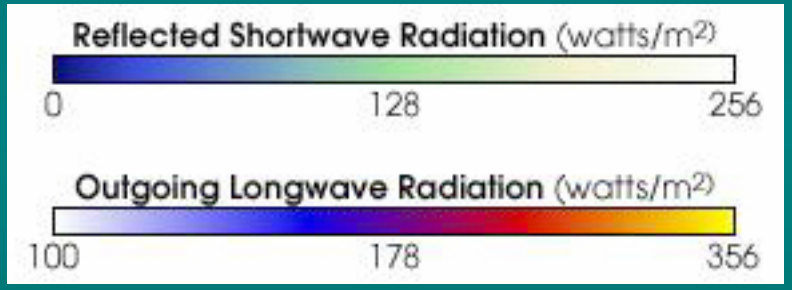
- NASA, TRMM, Terra & Aqua
  - launches 1997, 1999, 2002
  - 350 km orbit (35° inclination), 705 km polar orbits, descending (10:30 a.m.) & ascending (1:30 p.m.)
- Sensor Characteristics
  - 3 spectral bands
    - » Shortwave (0.3-5.0 μm)
    - » Window (8-12 μm)
    - » Total (0.3->200 μm)
  - Spatial resolution:
    - » 20 km
  - ±78° cross-track scan and 360° azimuth biaxial scan
  - 0.5% calibration accuracy
  - onboard blackbodies & solar diffuser



Shortwave and Longwave Radiation as Determined from Data of the Terra CERES

March 2000 – May 2001

QuickTime™ and a
decompressor
are needed to see this picture.



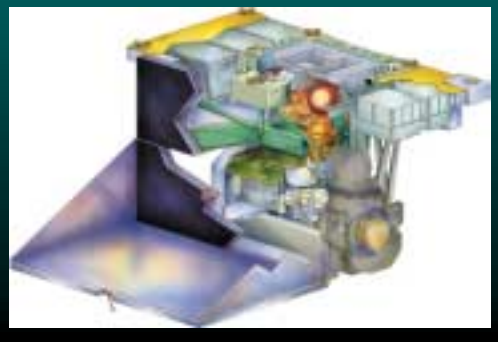
Longwave (on left): Radiation emitted to space from the Earth system

Shortwave (on right): Sunlight reflected back to space

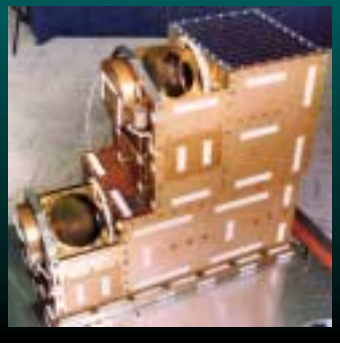
AIRS/AMSU/HSB

- High-spectral-resolution sounding suite measuring temperature and humidity profiles plus a wide variety of other variables
- The most advanced sounding system ever deployed in space
- 2382 visible and infrared channels on AIRS, plus 19 microwave channels on AMSU and HSB
- Horizontal resolutions of 13.5 km at nadir for AIRS and HSB, 40.5 km at nadir for AMSU
- Vertical resolutions of 1-2 km

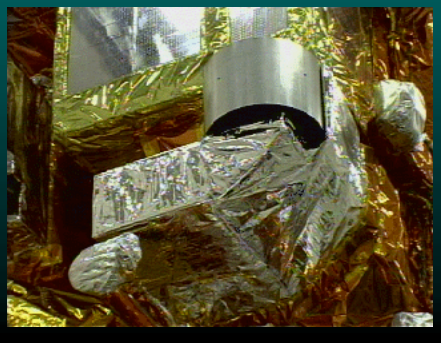
AIRS



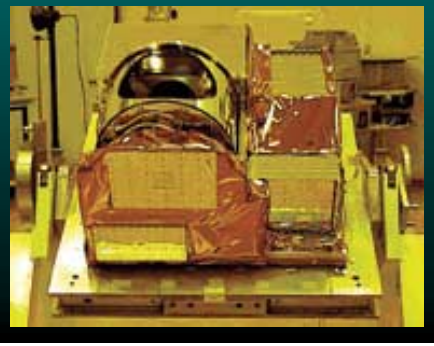
AMSU A1



AMSU A2



HSB

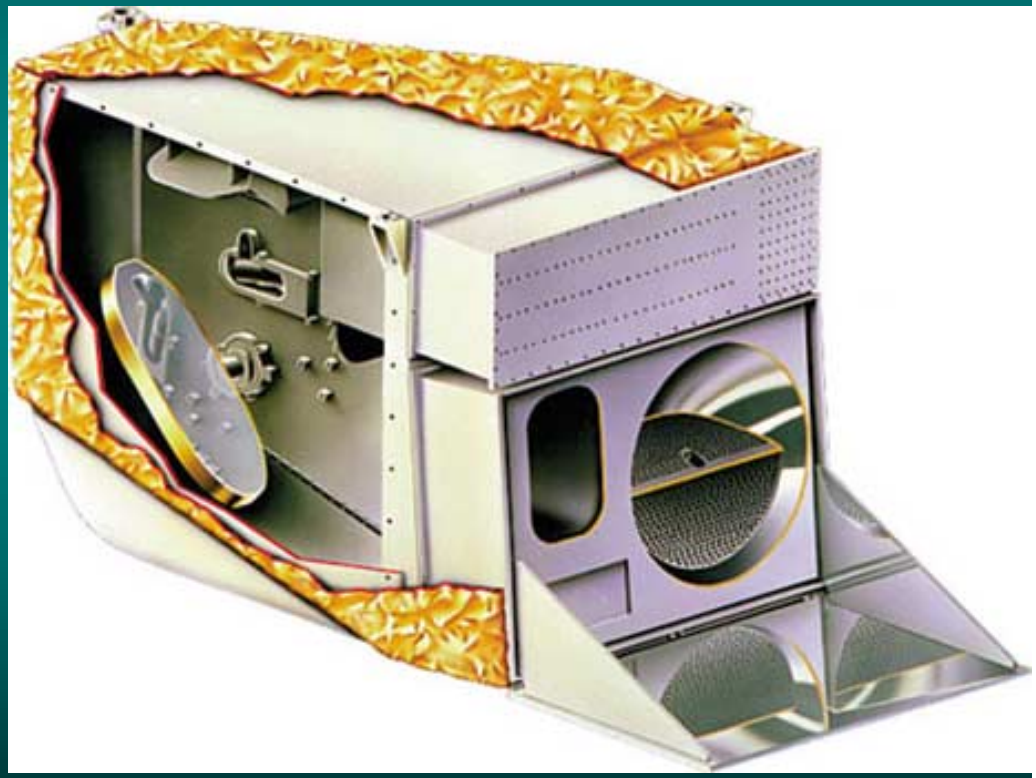


Advanced Microwave Scanning Radiometer (AMSR-E)

- NASA, Aqua
  - launches July 2001
  - 705 km polar orbits, ascending (1:30 p.m.)
- Sensor Characteristics
  - 12 channel microwave radiometer with 6 frequencies from 6.9 to 89.0 GHz with both vertical and horizontal polarization
  - conical scan mirror with 55° incident angle at Earth's surface
  - Spatial resolutions:
    - » 6 x 4 km (89.0 GHz)
    - » 75 x 43 km (6.9 GHz)
  - External cold load reflector and a warm load for calibration
    - » 1 K T_b accuracy

Moderate Resolution Imaging Spectroradiometer (MODIS)

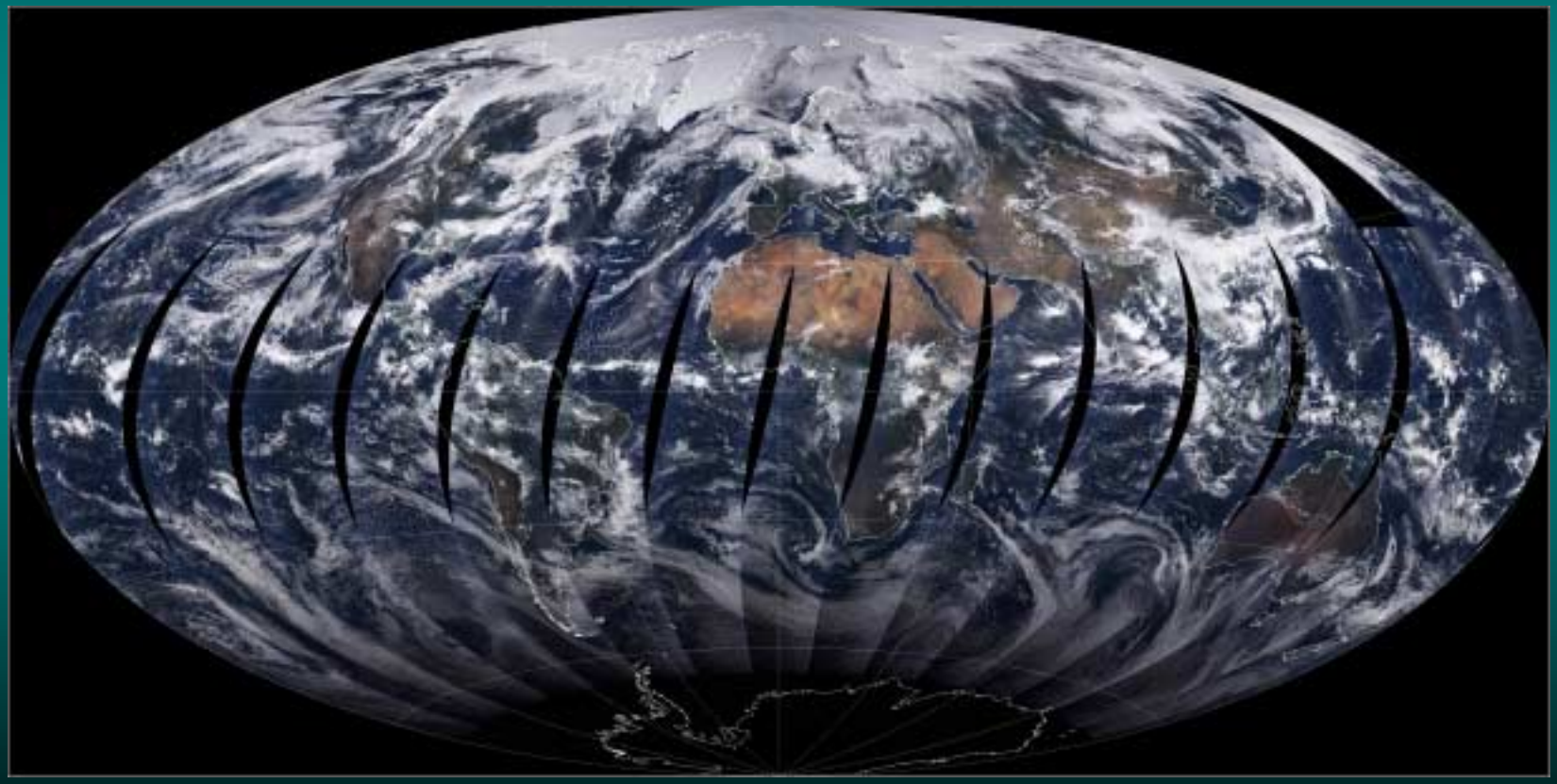
- NASA, Terra & Aqua
  - launches 1999, 2002
  - 705 km polar orbits, descending (10:30 a.m.) & ascending (1:30 p.m.)
- Sensor Characteristics
  - 36 spectral bands ranging from 0.41 to 14.385 μm
  - cross-track scan mirror with 2330 km swath width
  - Spatial resolutions:
    - » 250 m (bands 1 - 2)
    - » 500 m (bands 3 - 7)
    - » 1000 m (bands 8 - 36)
  - 2% reflectance calibration accuracy
  - onboard solar diffuser & solar diffuser stability monitor



Global Level-1B Composite Image

R = 0.65 μm
G = 0.56 μm
B = 0.47 μm

May 28, 2001

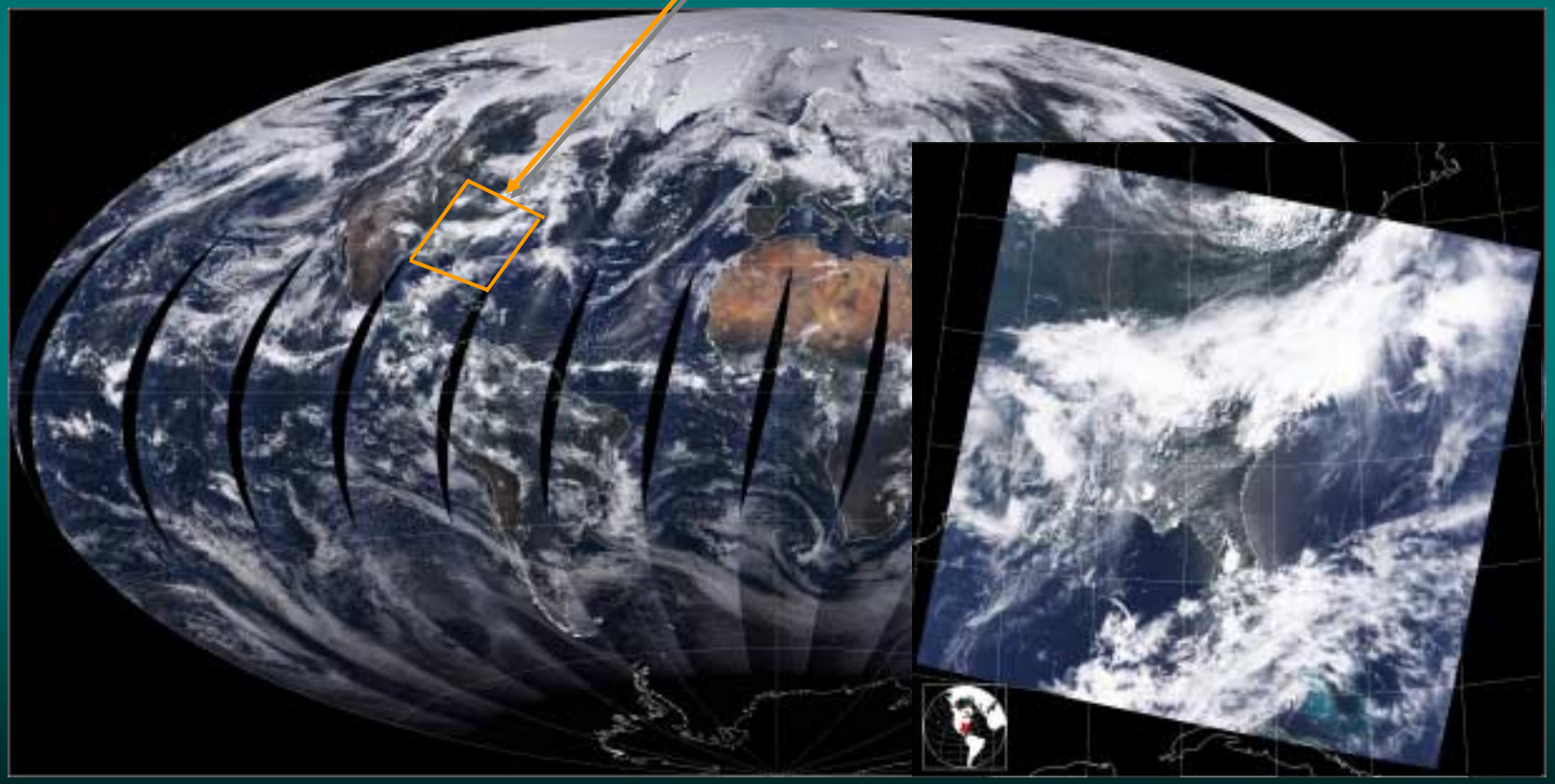


Global Level-1B Composite Image

R = 0.65 μm
G = 0.56 μm
B = 0.47 μm

May 28, 2001

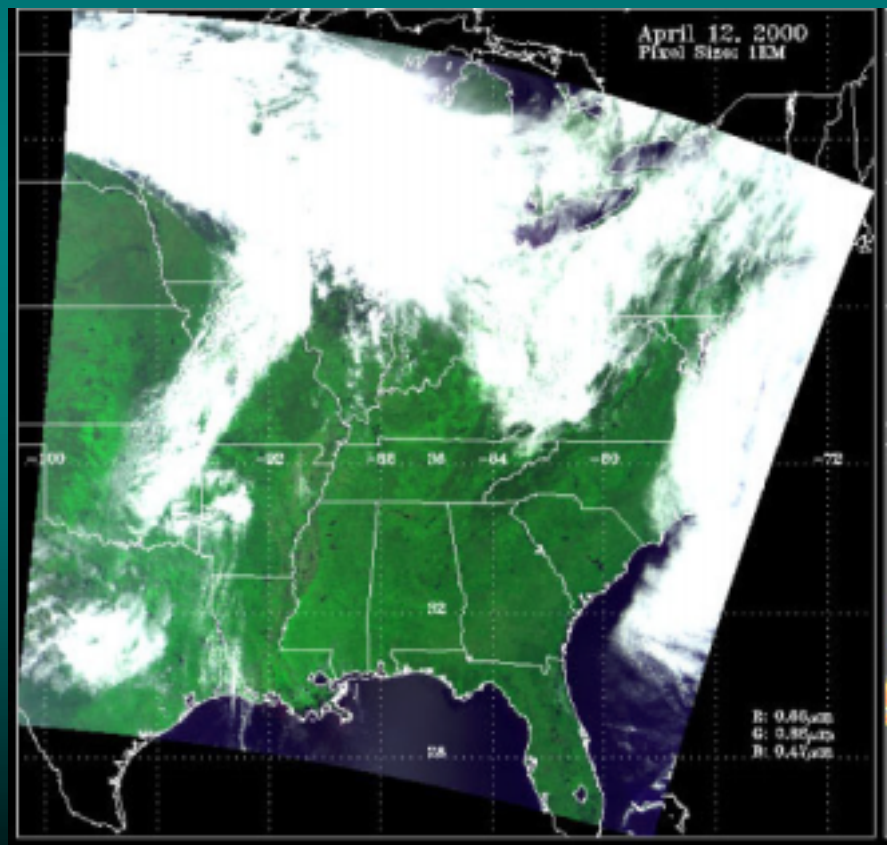
example data granule coverage (5 min)



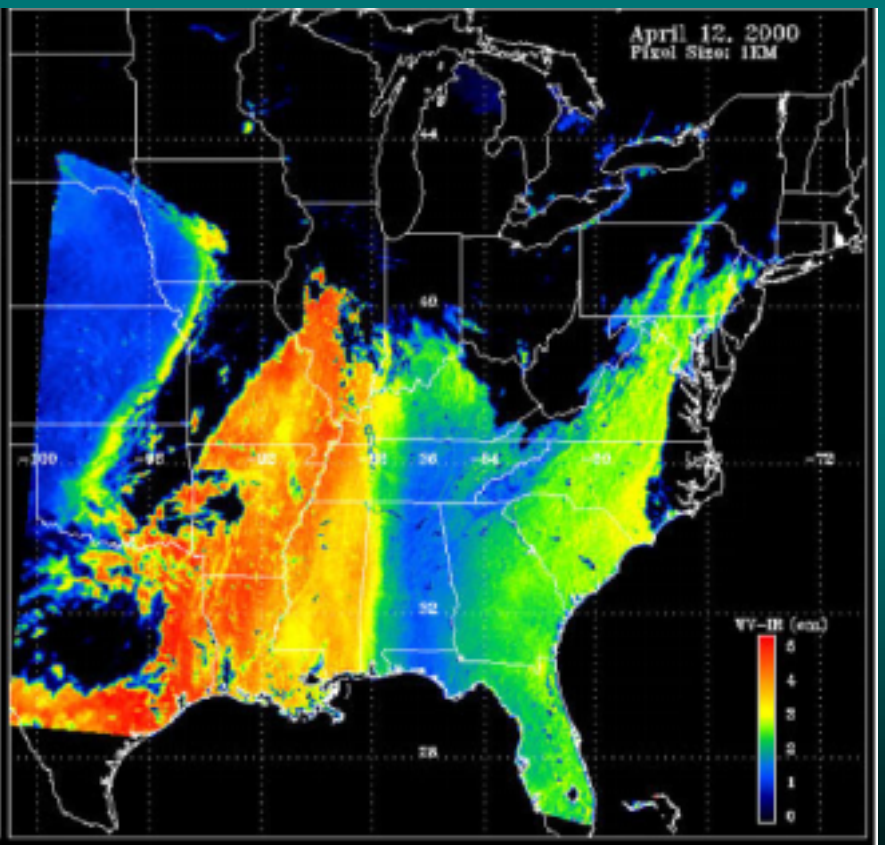
Atmospheric Water Vapor
(B. C. Gao – NRL)

April 12, 2000

R: 0.65, G: 0.86, B: 0.46



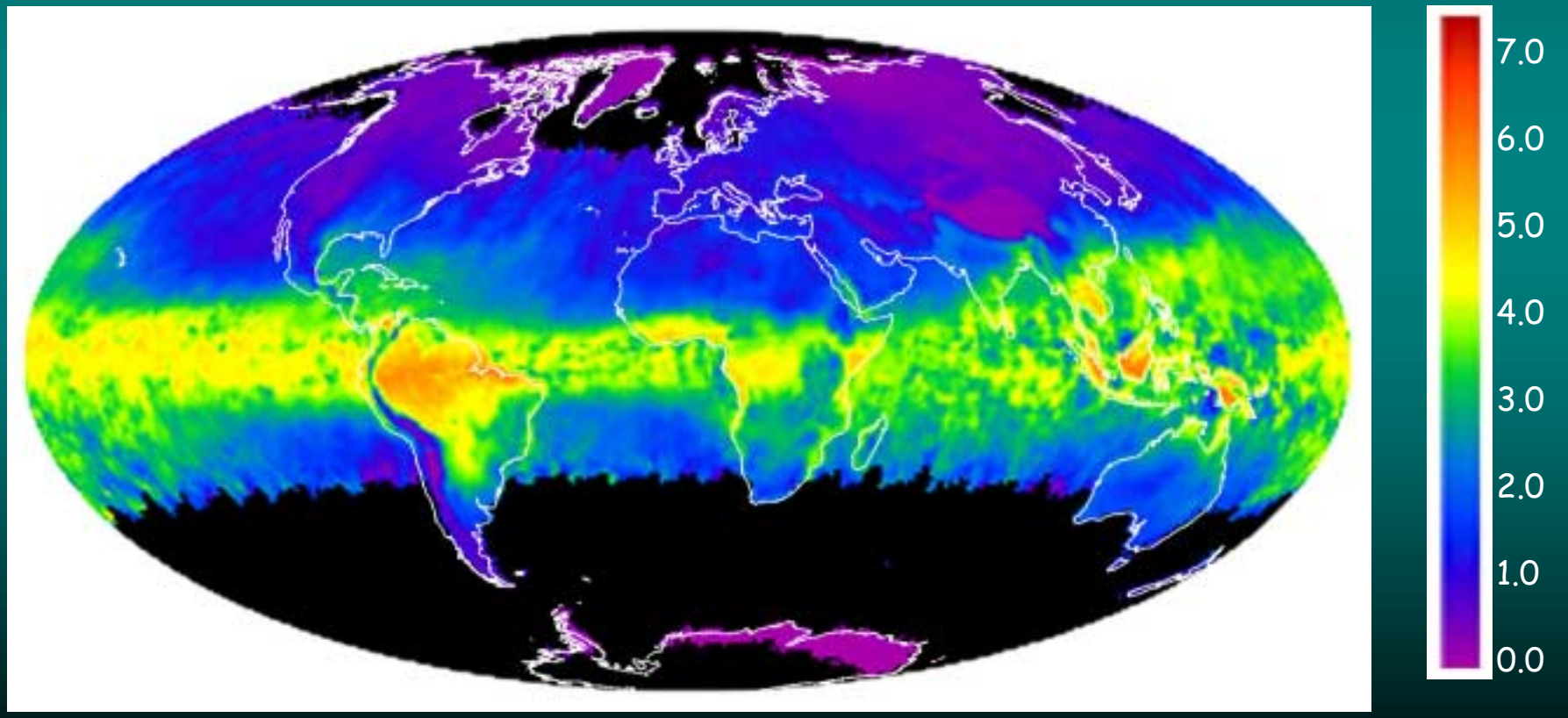
Precipitable Water Vapor (cm)



Precipitable Water over Land & Sunglint

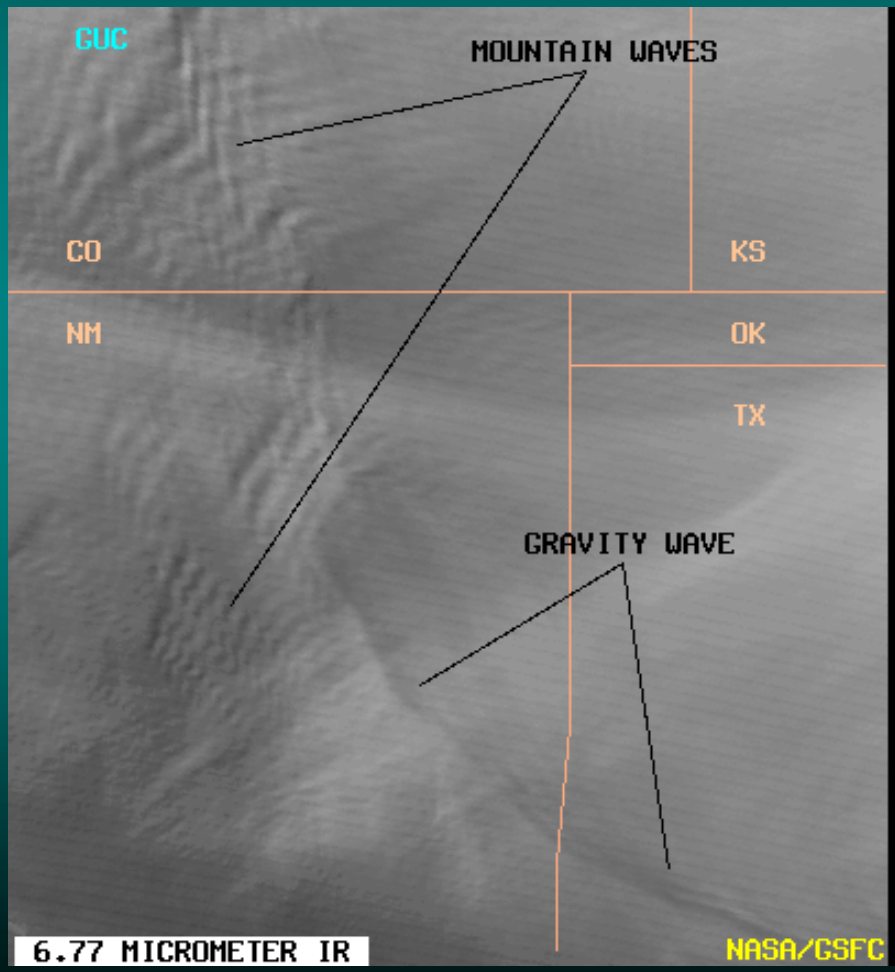
(B. C. Gao, et al. – Naval Research Laboratory)

Level-3 Monthly
April 2001

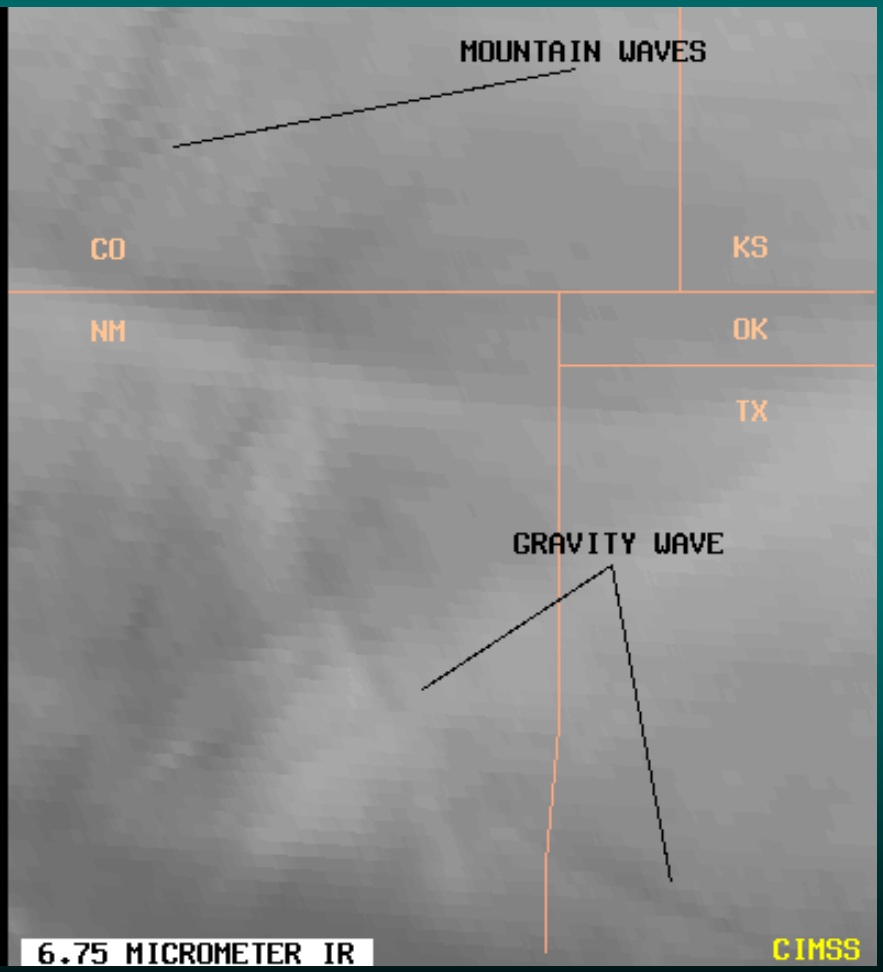


MODIS Reveals Atmospheric Moisture Details As Never Seen Before

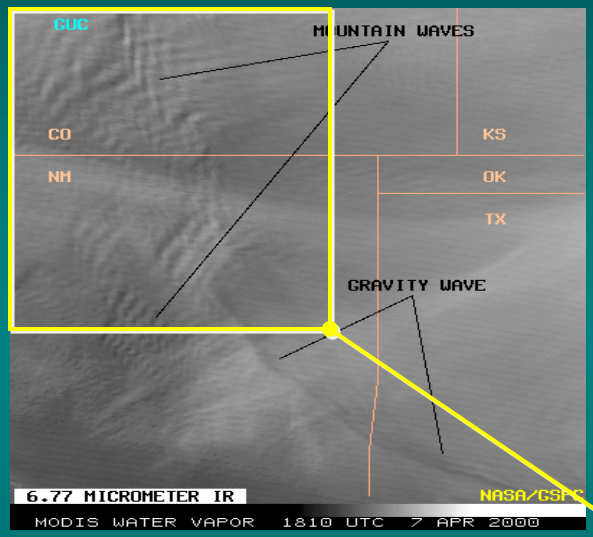
MODIS Water Vapor (1 km)

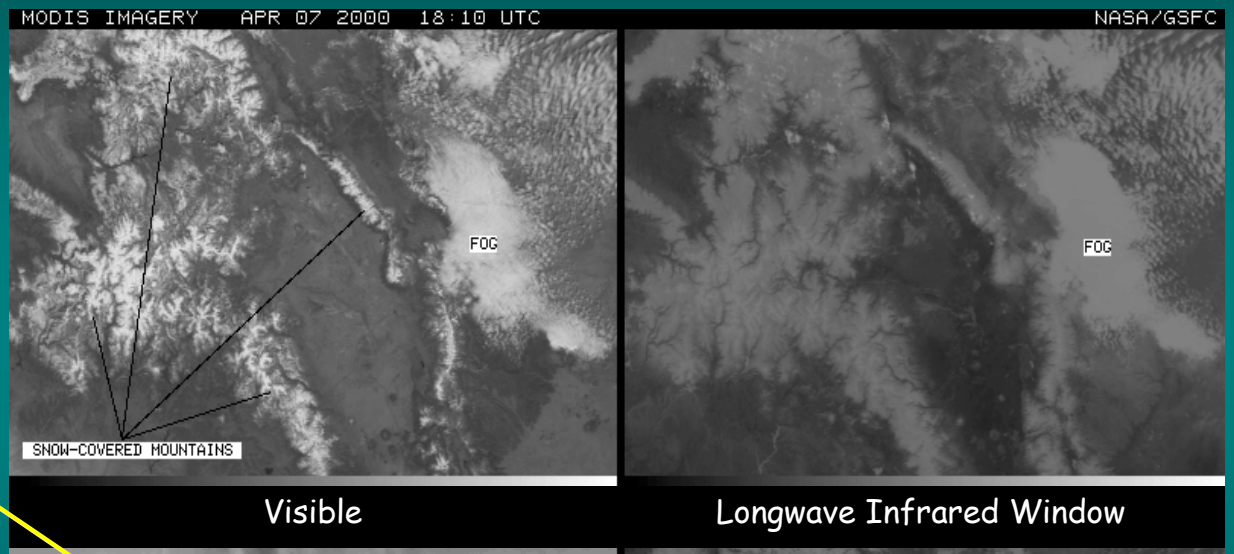


GOES-8 Water Vapor (4 x 8 km)



Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery





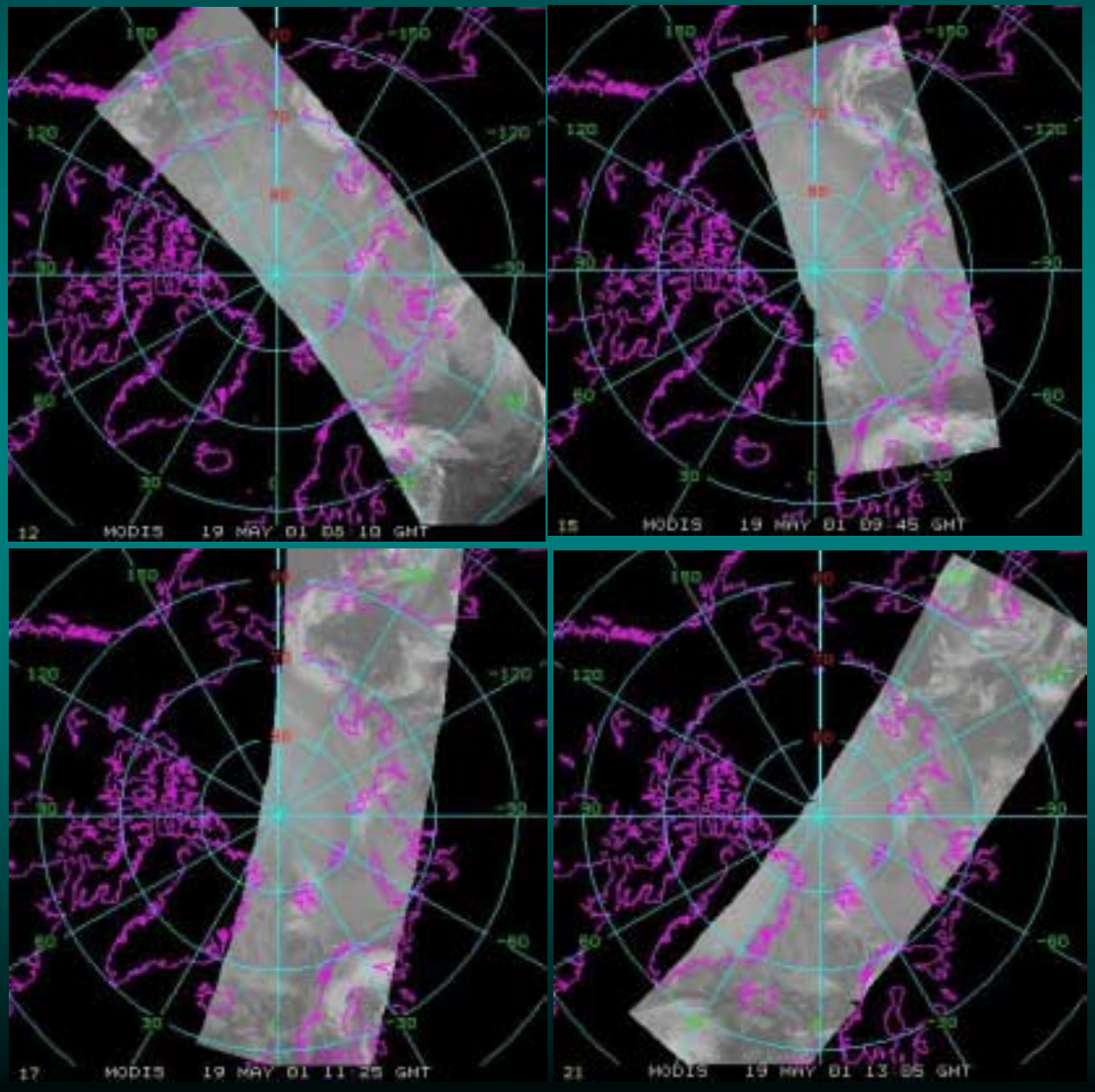
Visible

Longwave Infrared Window

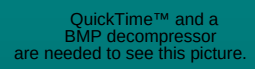
MODIS Water Vapor (1 km)

Shortwave Infrared Window

Every 100 Minutes MODIS Covers the Polar Regions

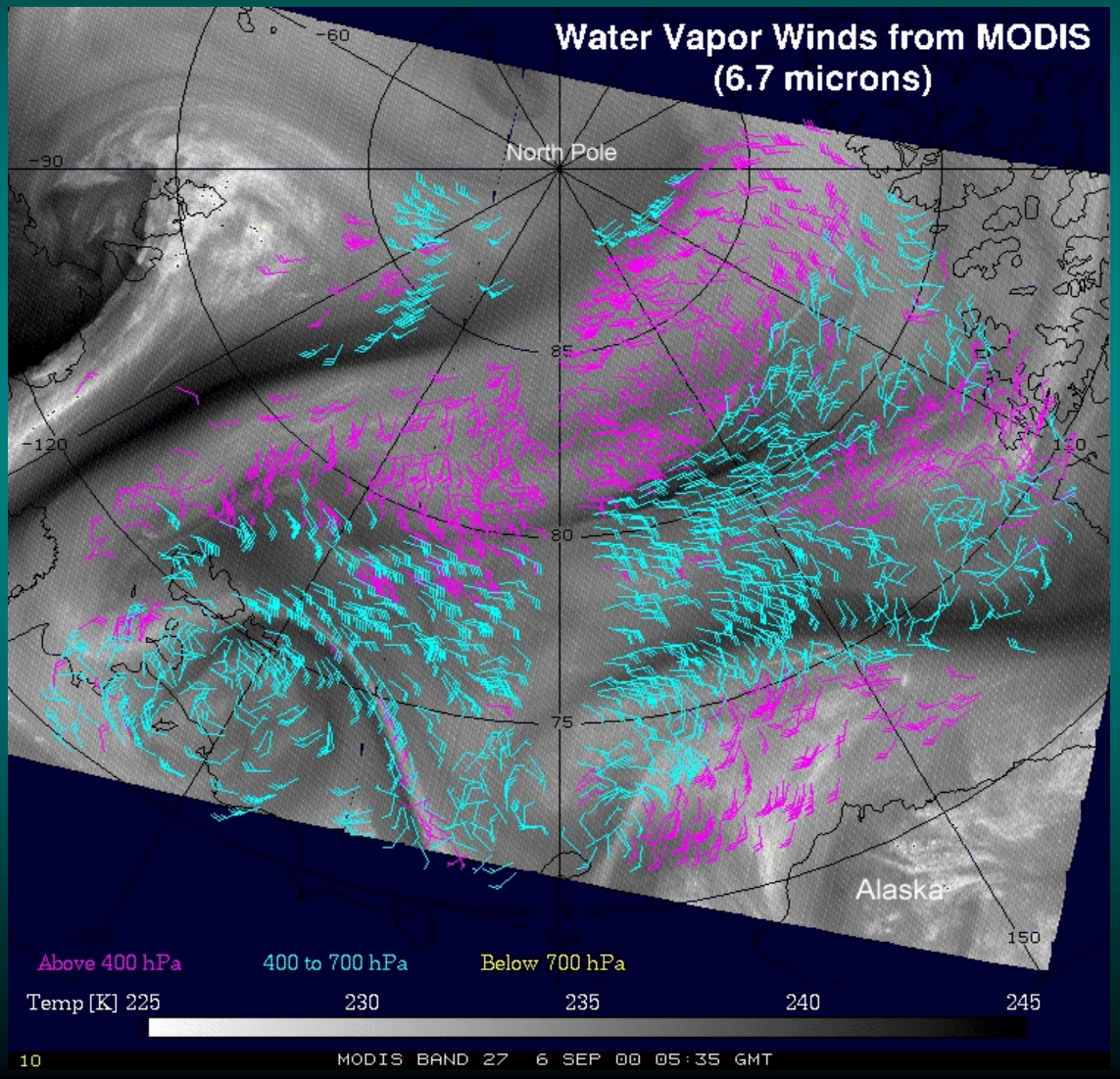


Every 100 Minutes MODIS Covers the Polar Regions



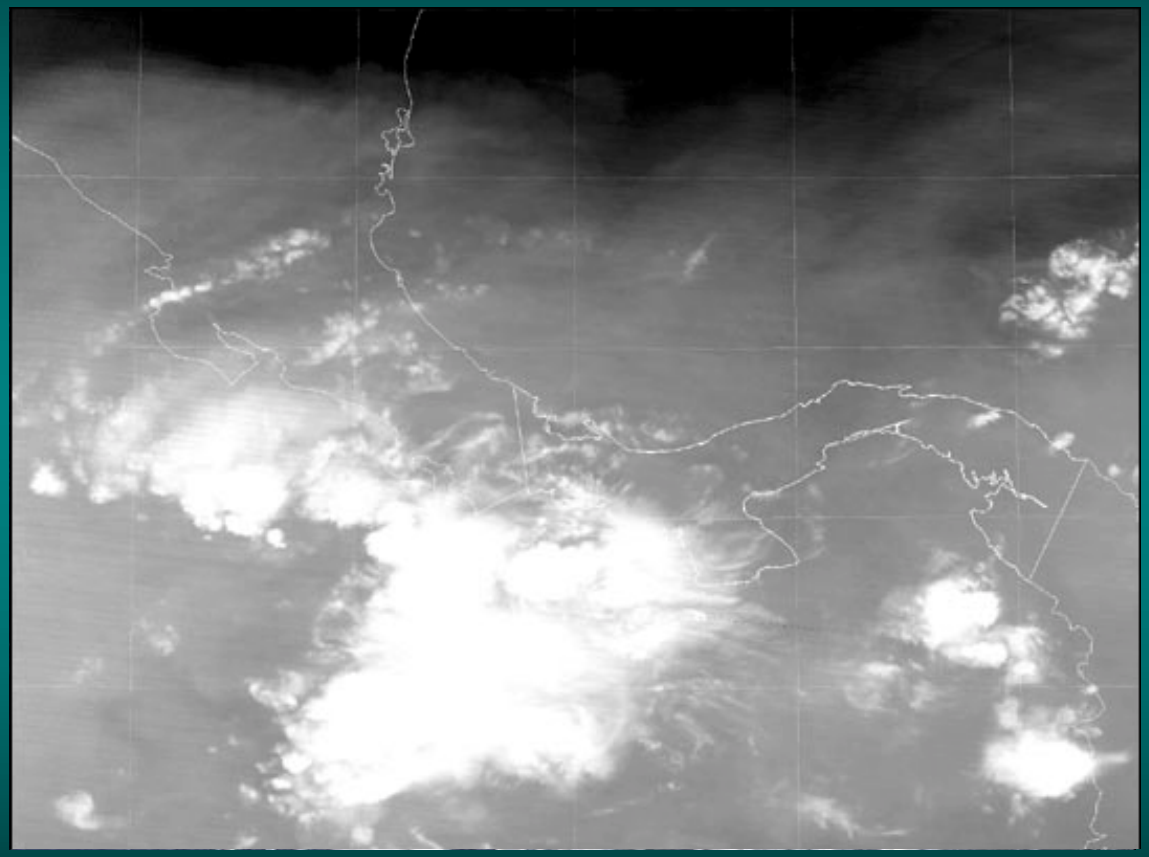
Winds from MODIS: An Arctic Example

Cloud Tracked Winds
Water Vapor Winds



MODIS Detects Subvisible Cirrus

True Color Image
Subvisible Cirrus (1.38 μm)

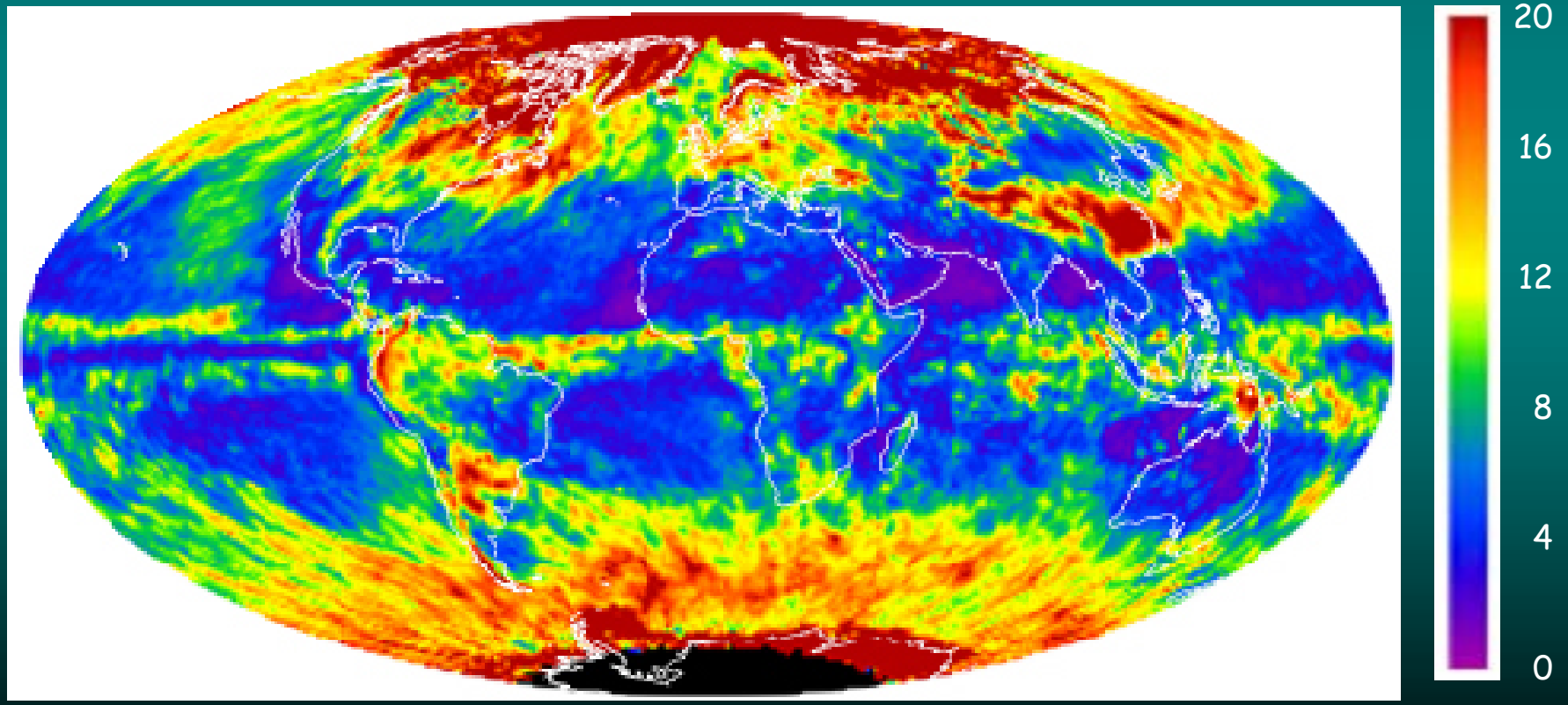


Central America
April 4, 2000

Cloud Optical Thickness

(M. D. King, S. Platnick, M. Gray, E. Moody, et al. – NASA GSFC, UMBC)

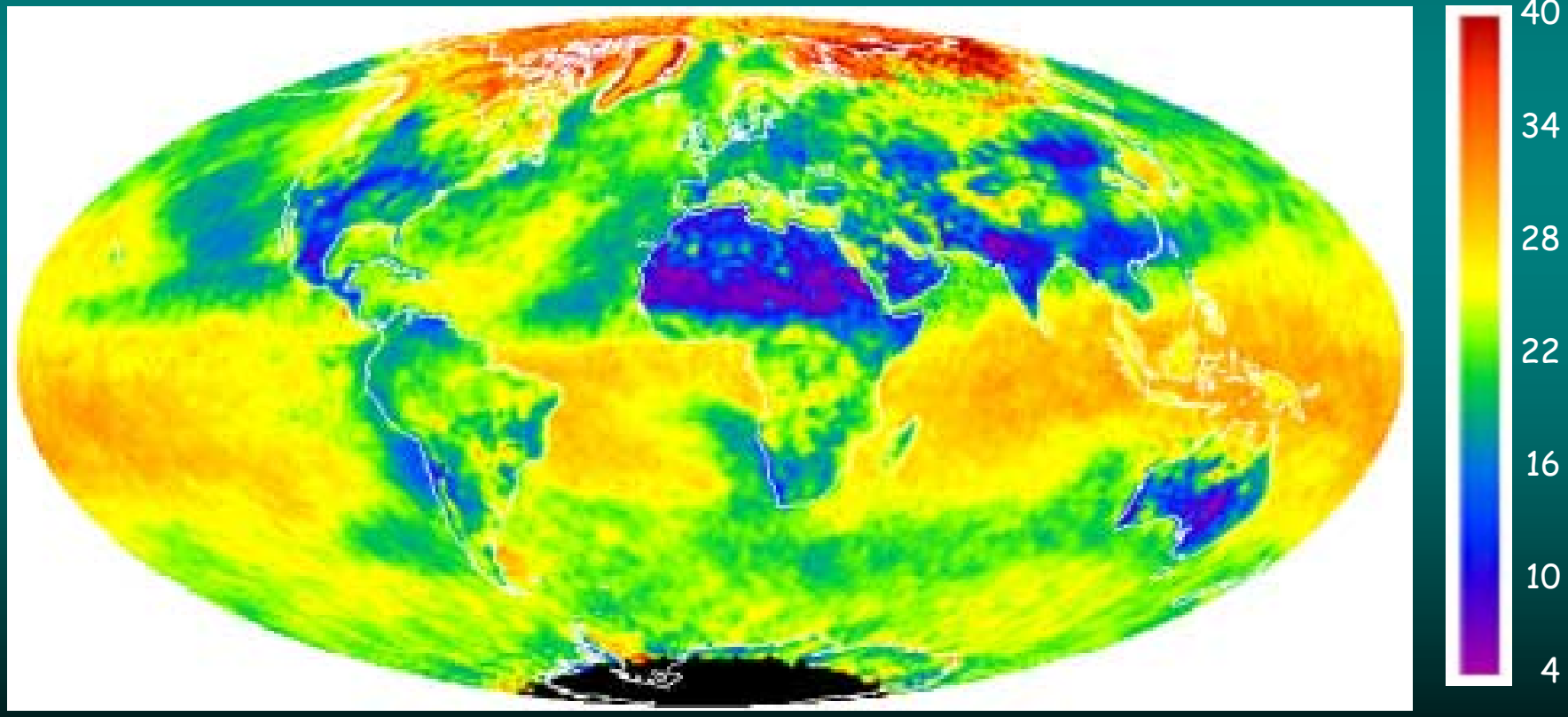
Level-3 Monthly
April 2001



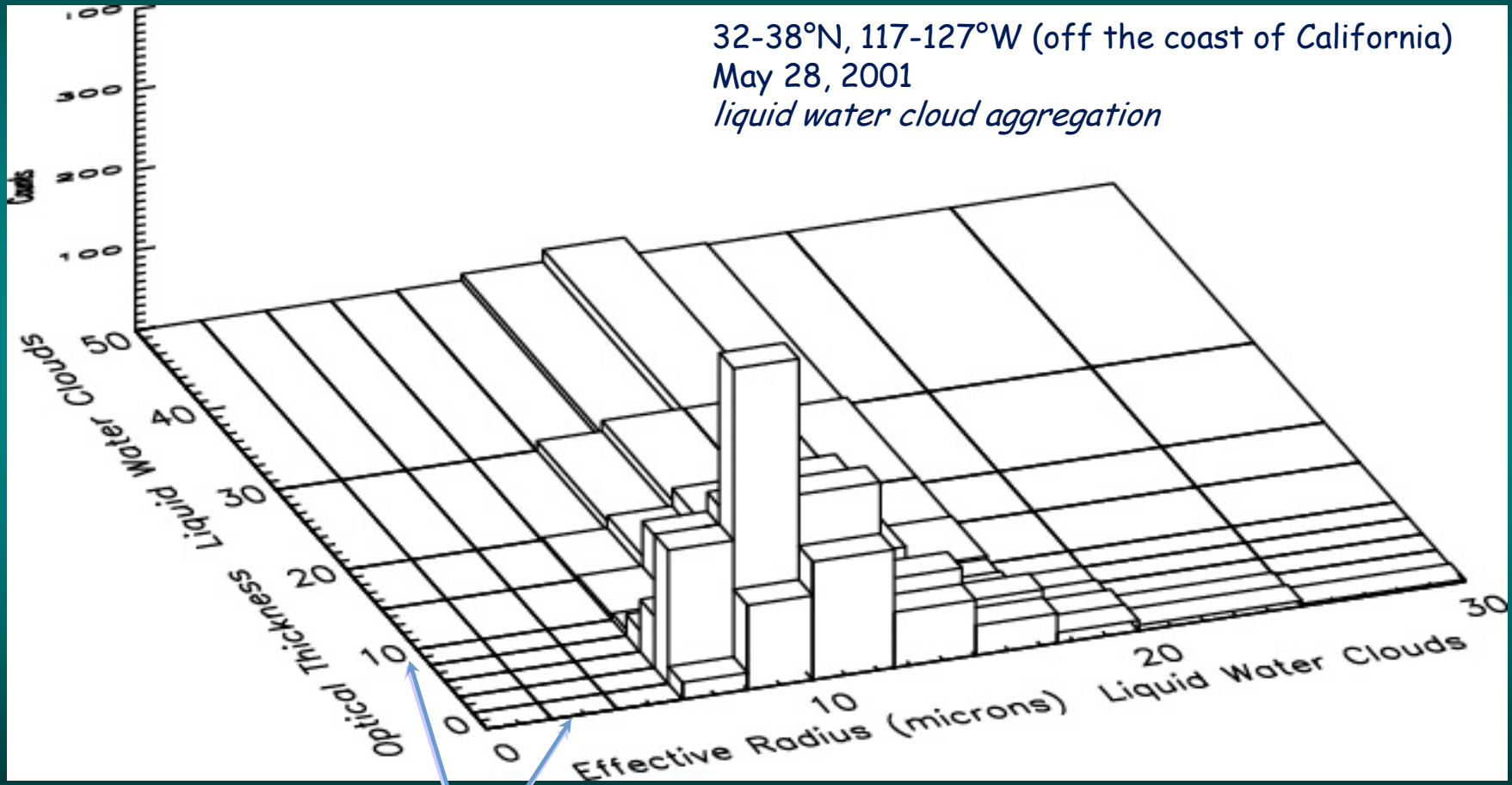
Cloud Effective Particle Radius

(M. D. King, S. Platnick, M. Gray, E. Moody, et al. – NASA GSFC, UMBC)

Level-3 Monthly
April 2001



Joint Histogram of Cloud Optical Thickness & Effective Radius



Level-2 Global Cloud Images

True Color Image

Cloud Mask

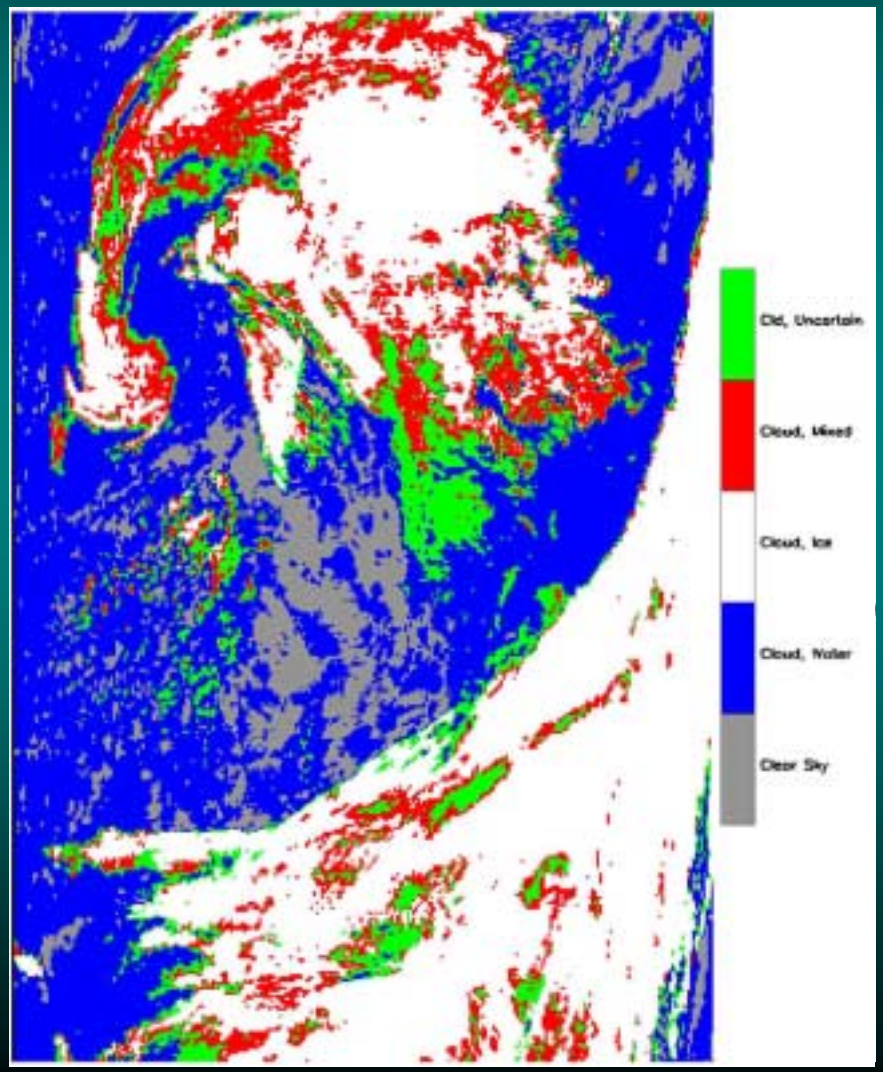
Land Classification

Cloud Optical Thickness

Cloud Effective Radius

Cloud Top Temperature

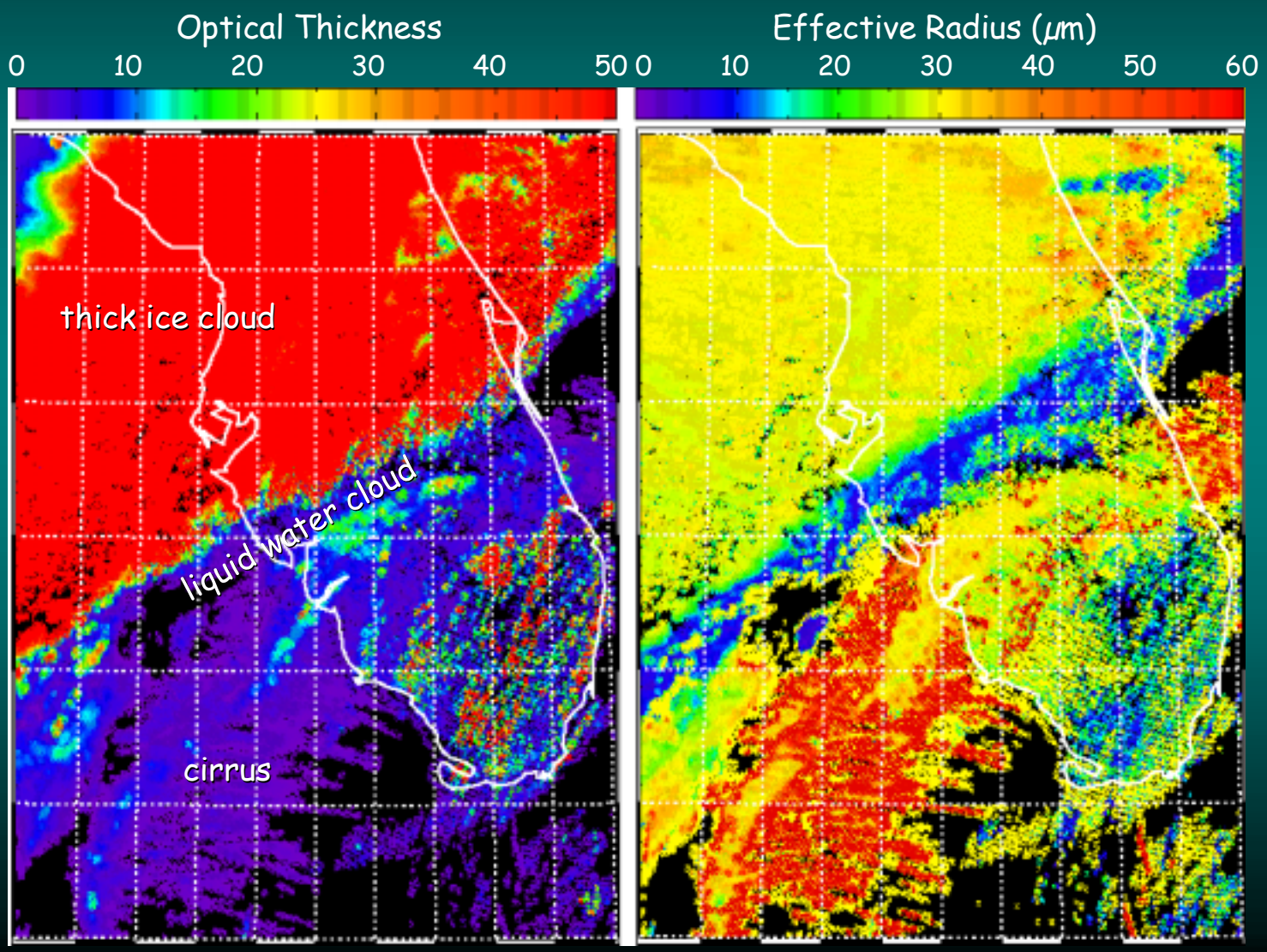
Bispectral Phase

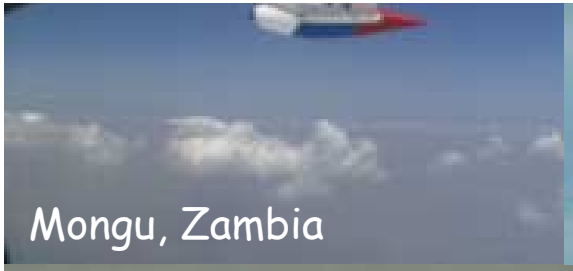


October 1, 2001

MODIS Retrieval of Cloud Optical Thickness & Effective Radius over Florida

March 4, 2001




Mongu, Zambia

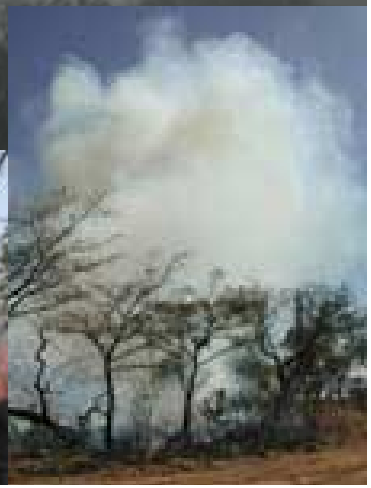

JR-690


CV-580


ER-2

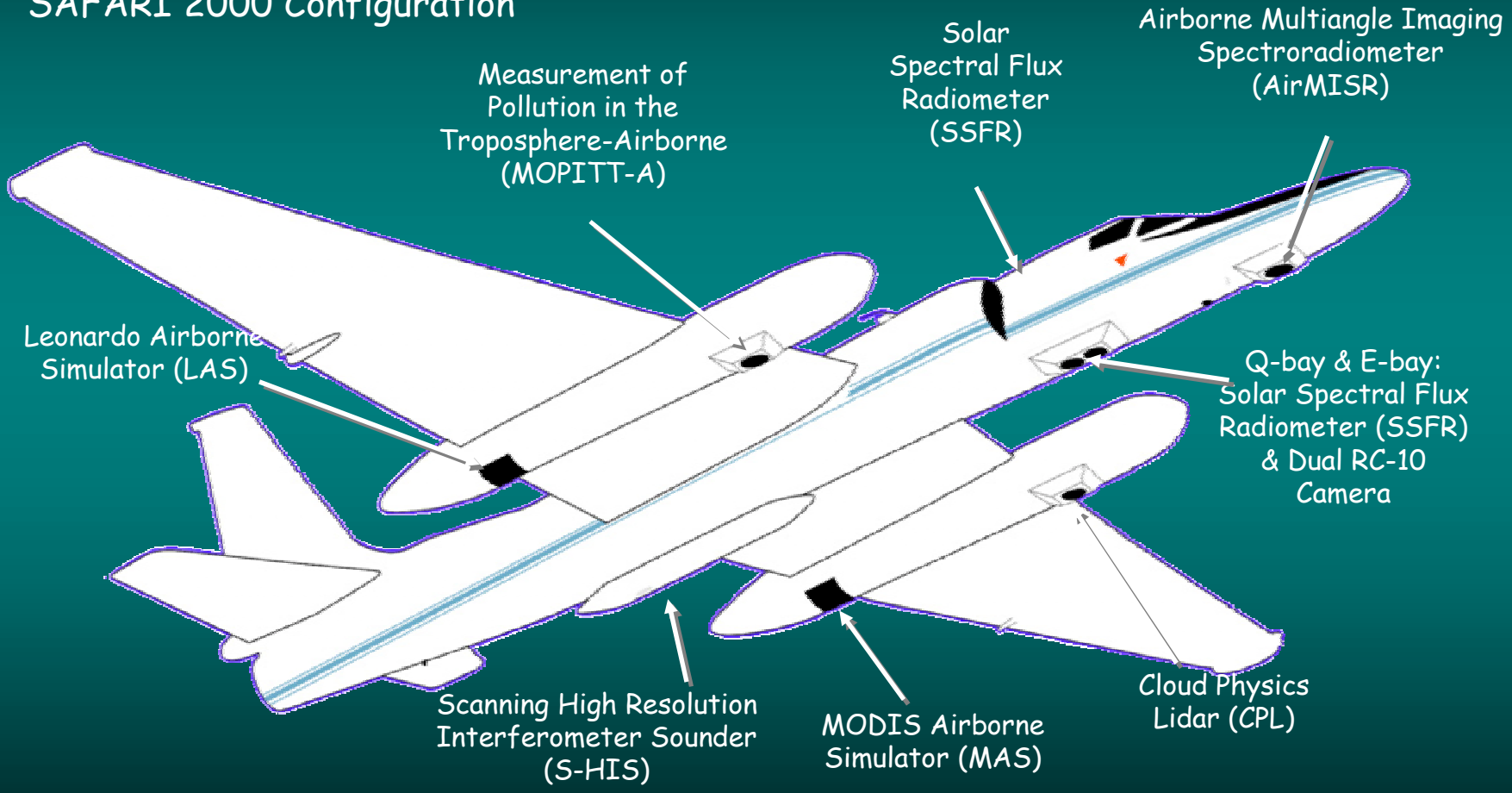
August 12- September 25, 2000

SAFARI 2000

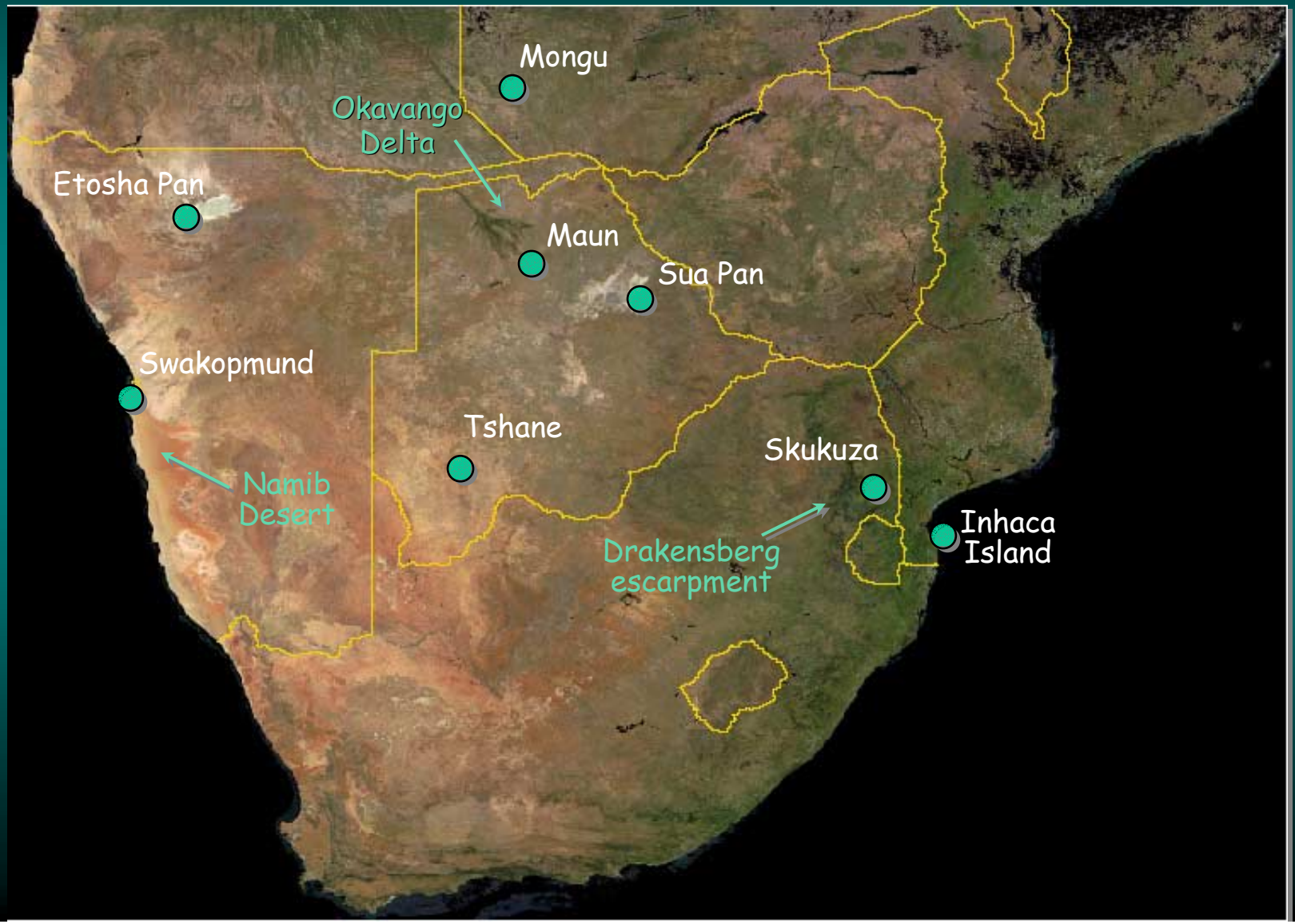


NASA ER-2 Aircraft

SAFARI 2000 Configuration

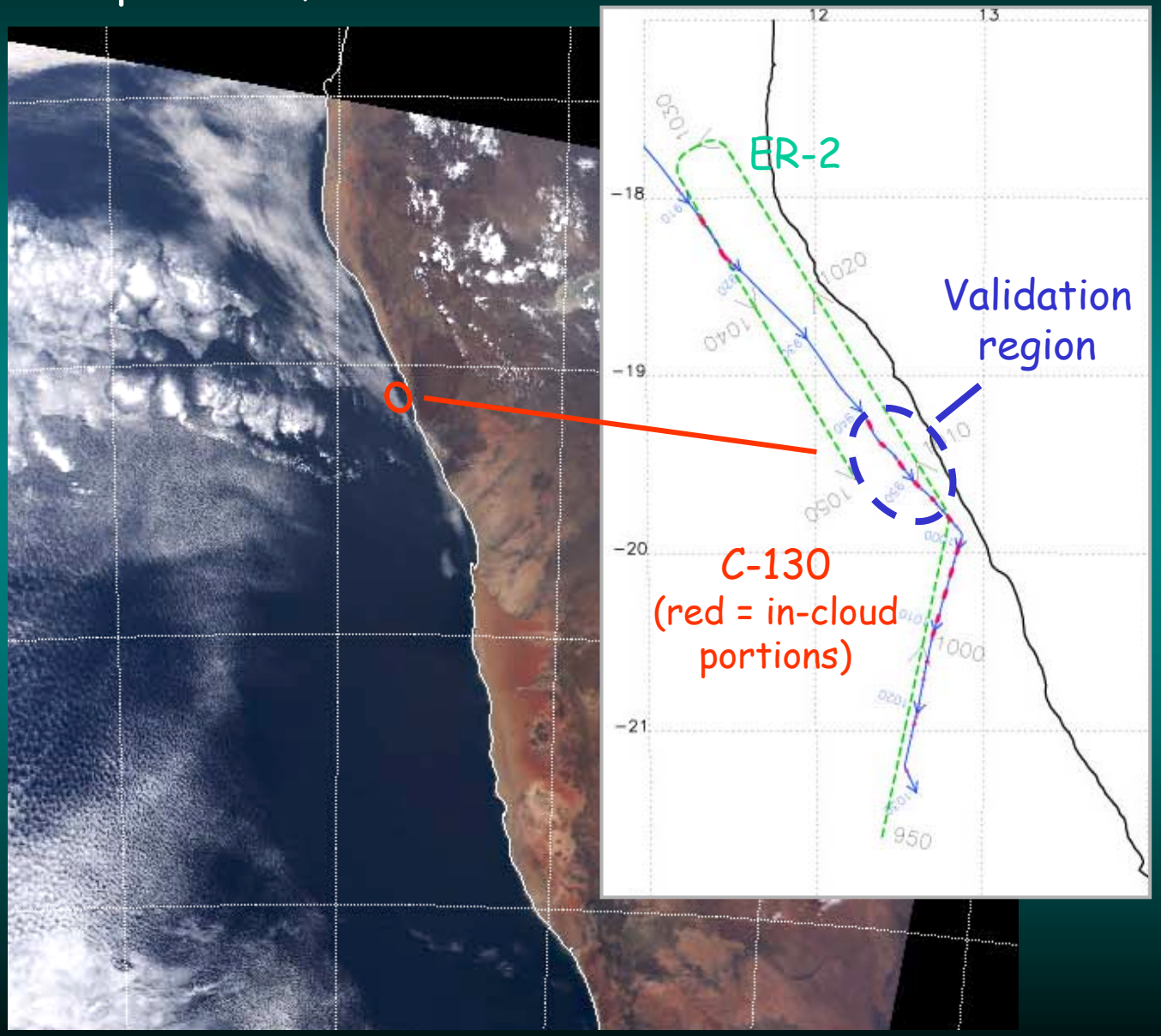


SAFARI 2000 Core Sites

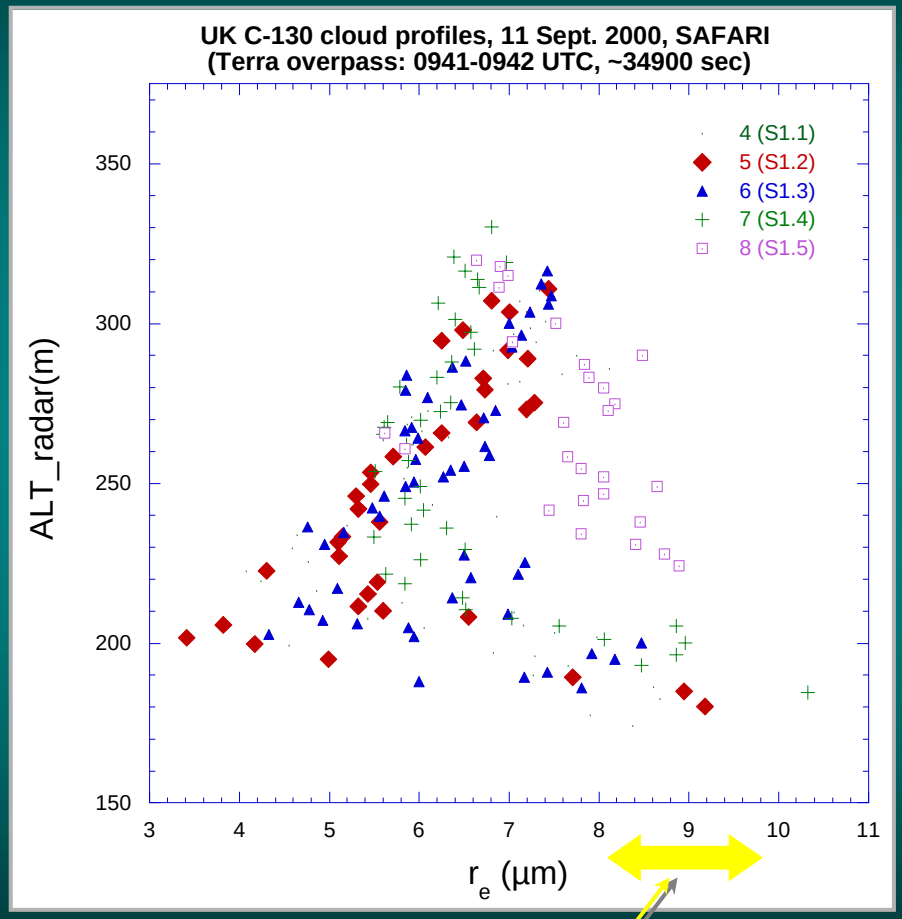


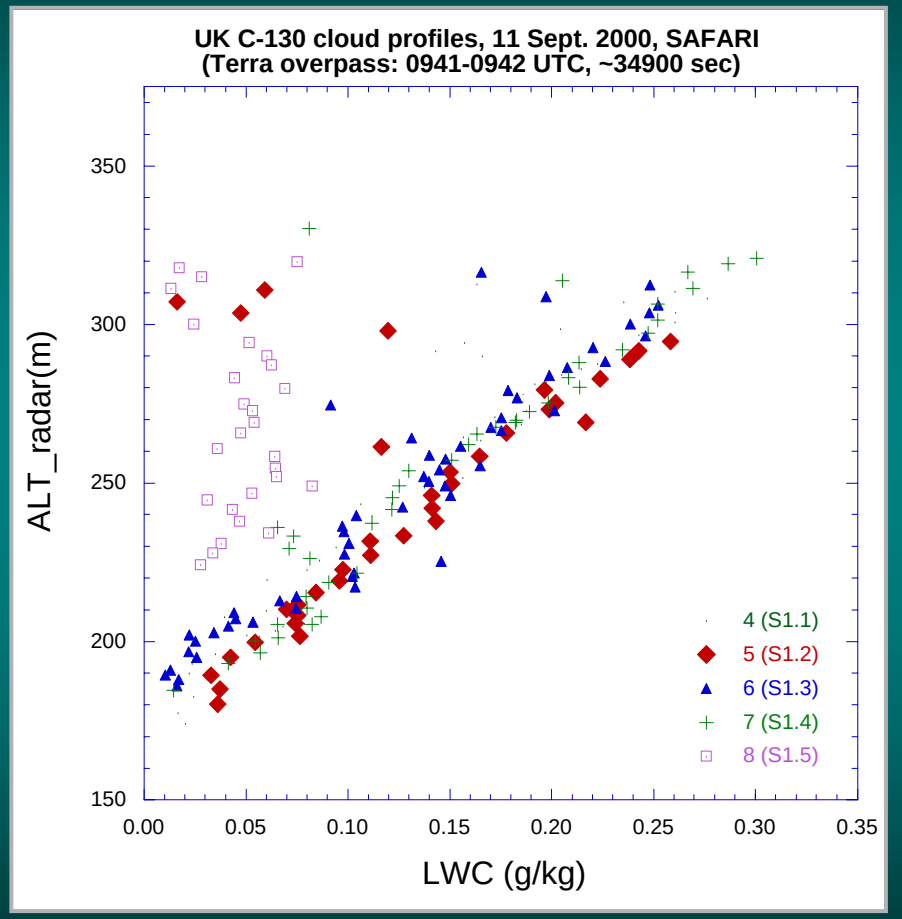
MODIS true color
11 Sept. 2000, 0940 UTC

ER-2, C-130
ground tracks



UK C-130 in situ droplet radius, liquid water content
11 Sept. 2000, 0941-0953 UTC (S. Osborne, Met Office)



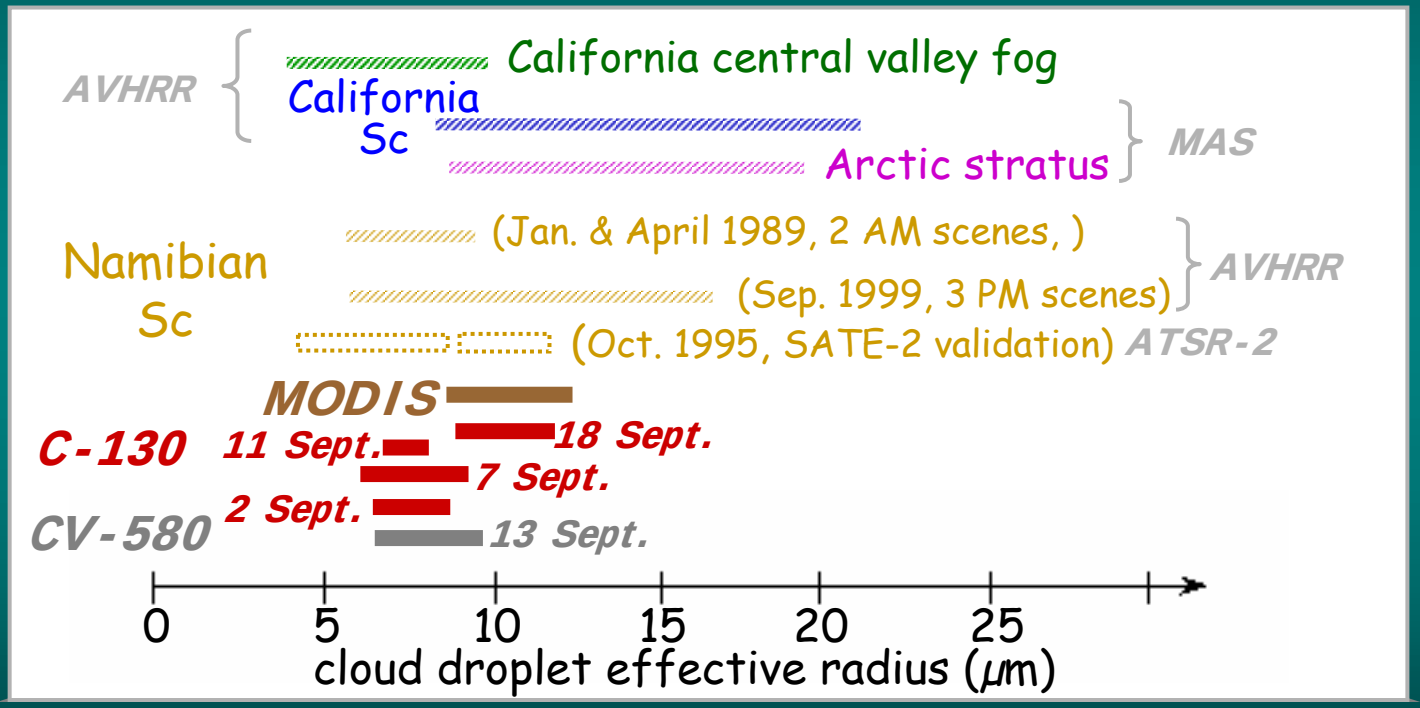


MODIS droplet size retrievals

optical thickness: C-130 ≈ 5, MODIS ≈ 3±1

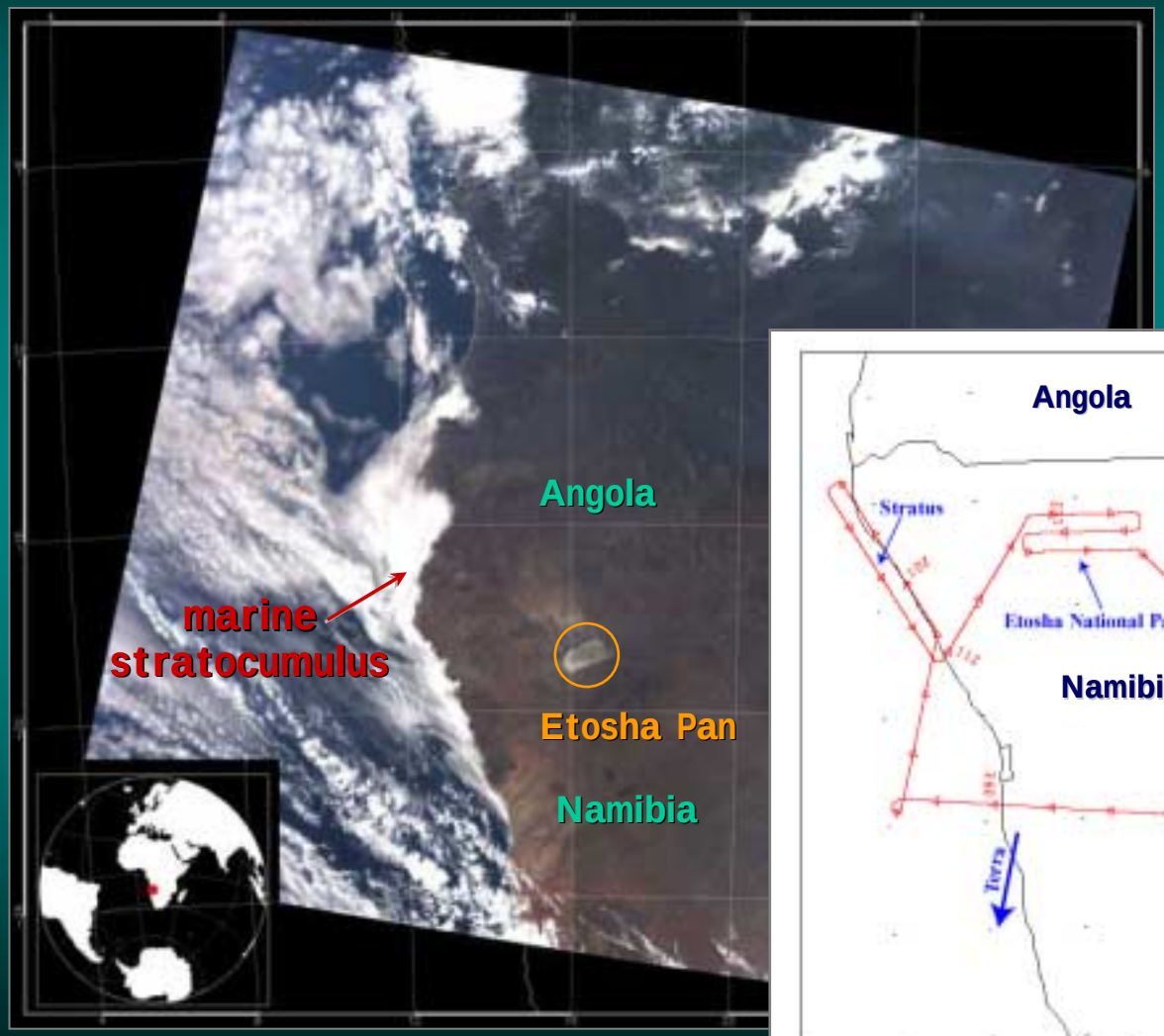
Platnick et al. (2002)

Previous + SAFARI 2000 Namibian Sc studies



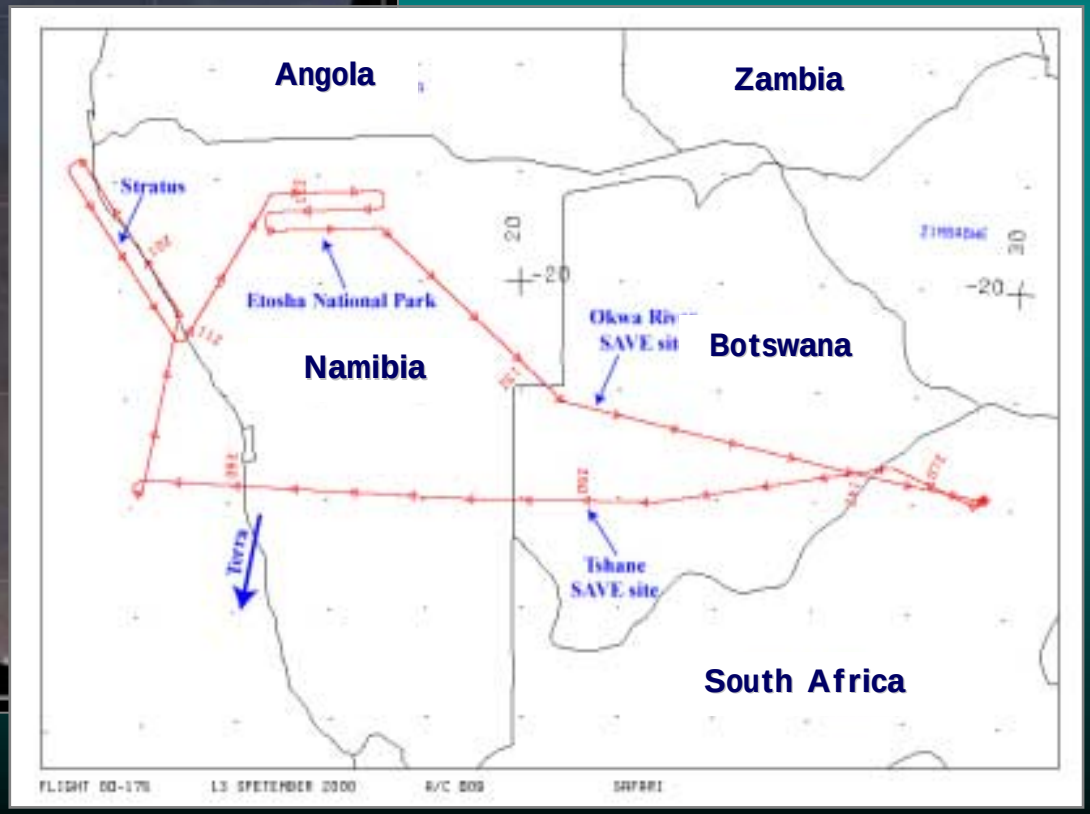
Namibian Sc often have significantly smaller droplet sizes than other regimes? Or lack the larger droplet sizes of other regimes? A difference in CCN concentrations? If so, why?

Level-1B Image of Namibian Stratus during SAFARI 2000



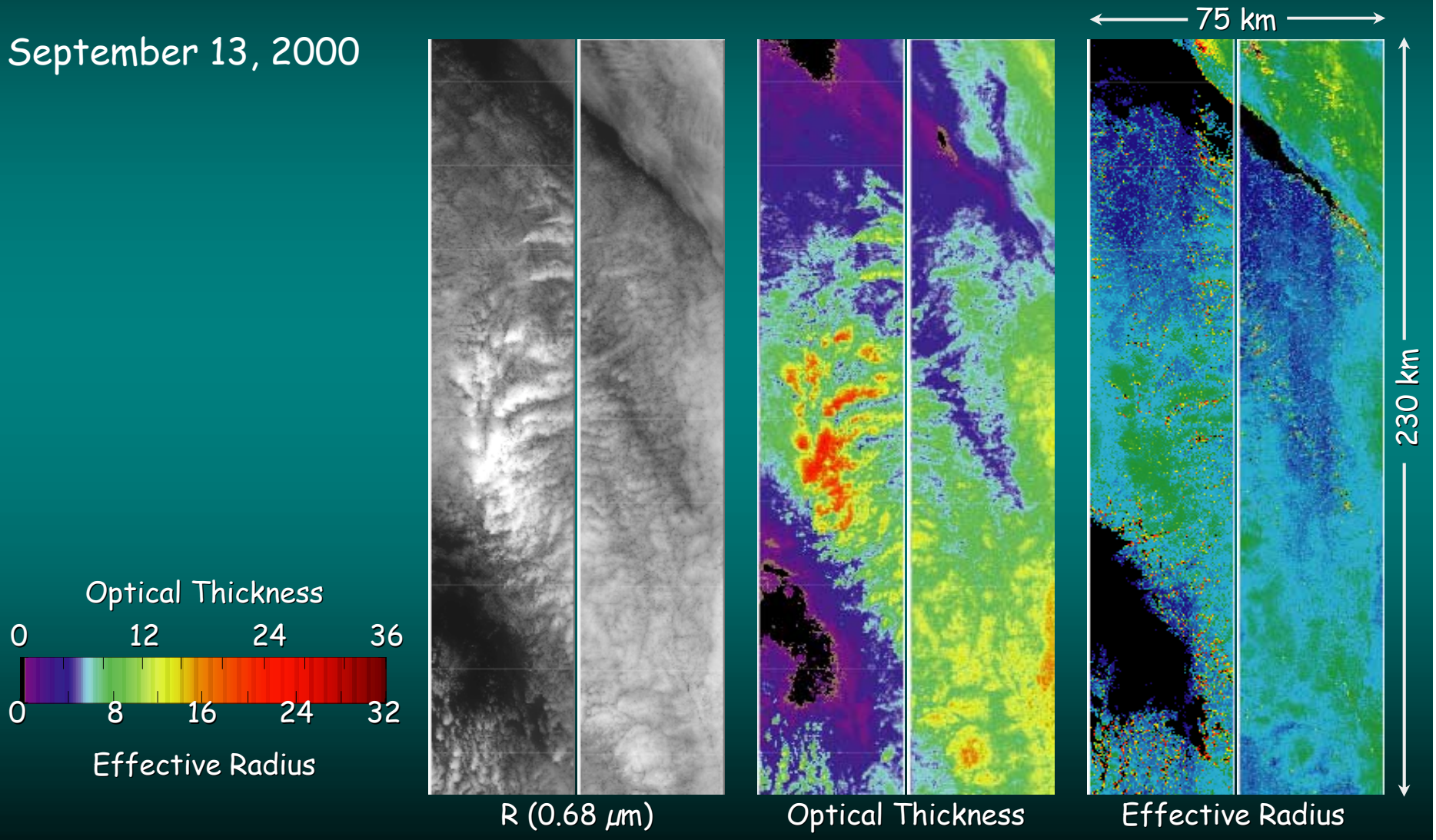
September 13, 2000

ER-2 ground track



MODIS Airborne Simulator Analysis of Namibian Stratus during SAFARI 2000

September 13, 2000



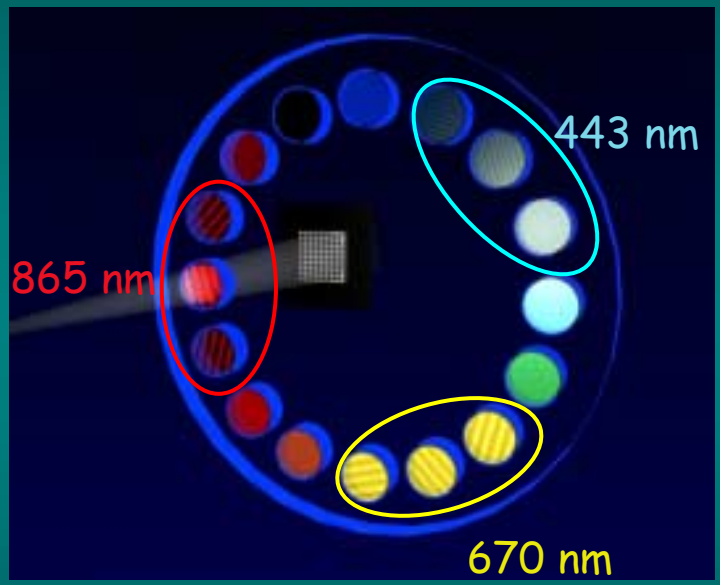
POLDER Characteristics

POLarization and Directionality of the Earth Reflectances

Wide field of view :
±43° along track
±51° cross track

CCD Matrix: 242 x 274 detectors

Filters wheel with up to 9 spectral bands in VIS/NIR and 3 polarized channels (443, 670 and 865 nm)



POLDER wide FOV and CCD matrix allow for :
- Instantaneous observation of the scene within FOV
- Multi-angle measurements of total and polarized radiances (3 bands)

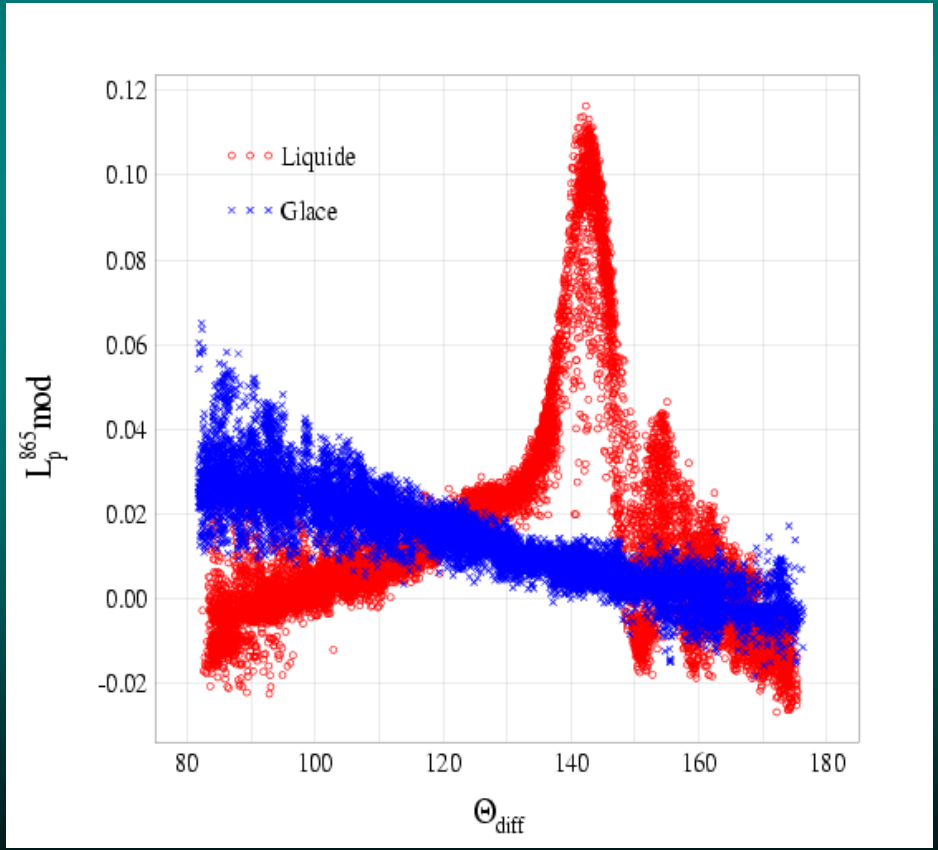
Cloud Top Phase Analysis with POLDER

Total Radiance

QuickTime™ and a
GIF decompressor
are needed to see this picture.

Polarized Radiance

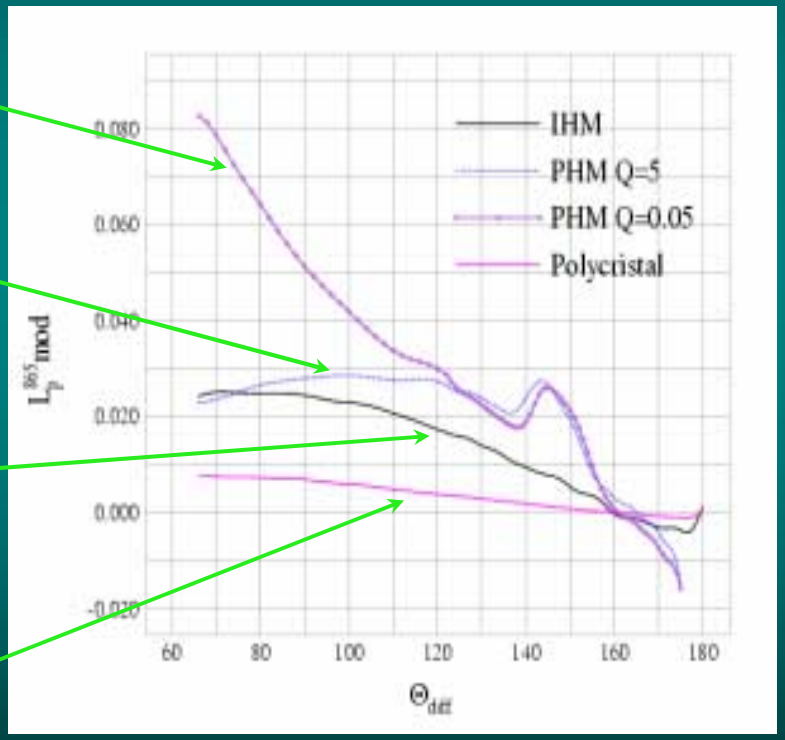
Liquid and Ice clouds are easily distinguished using multiangle polarized radiance measurements

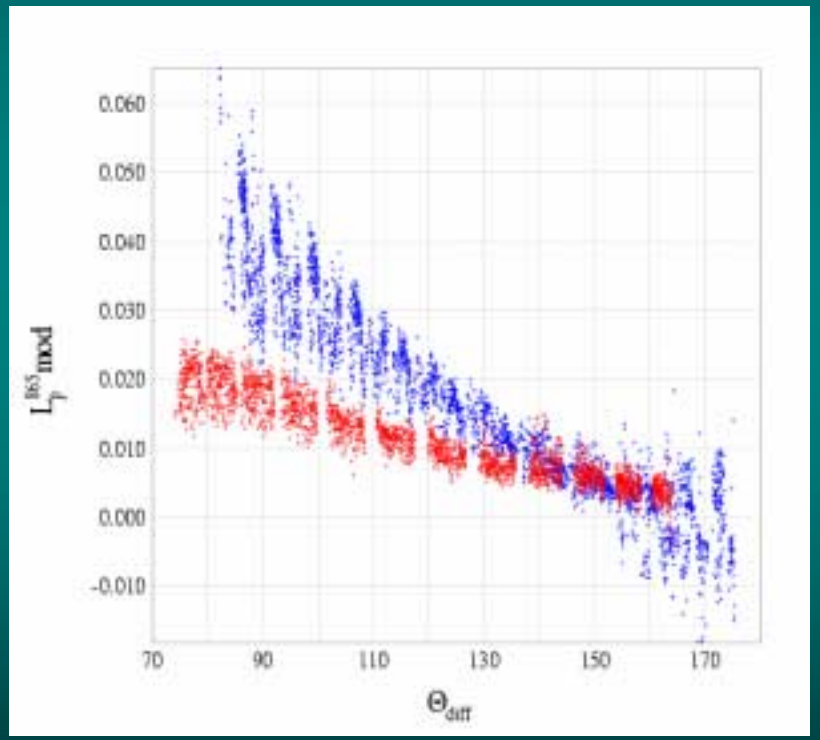


Deriving Crystal Shape from POLDER using Multiangle Polarization Measurements

Simulations

Observations



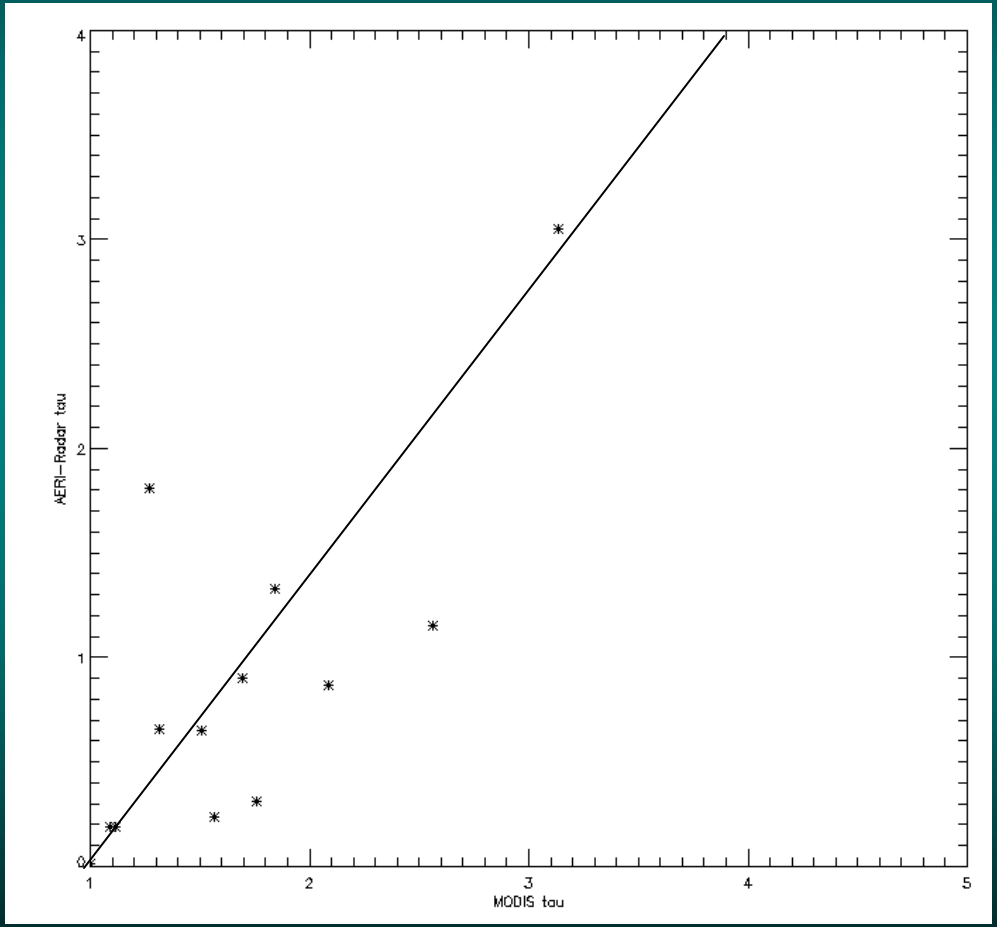


Polarized radiance as a function of scattering angle

Comparison of Visible Optical Thickness

(G. G. Mace, S. Bensen, K. Sassen – University of Utah)

Retrieved Optical Thickness



MOD06 Optical Thickness

Summary

- During CRYSTAL-FACE, Aqua will be in orbit at 1:30 pm ascending orbit (solar time) and Terra will be in orbit at 10:30 am descending orbit
  - MODIS and CERES retrieve cloud optical and microphysical properties using related, but different, algorithms for cloud mask, thermodynamic phase, and optical and physical cloud properties
  - AIRS/AMSU/HSB and AMSR-E will be recently launched into orbit and will enable details of temperature and moisture structure, sea surface temperature, and integrated liquid water path
- Airborne and spaceborne intercomparisons
  - Require coordination of high altitude, in situ, and low altitude aircraft along similar flight paths at time of satellite overpass
    - » Parallel to satellite orbit track not required
    - » Valuable for confirming thermodynamic phase and microphysical characteristics of the water and ice clouds
- Surface remote sensing intercomparisons
  - Requires overflights of surface sights with both satellite and aircraft on numerous occasions

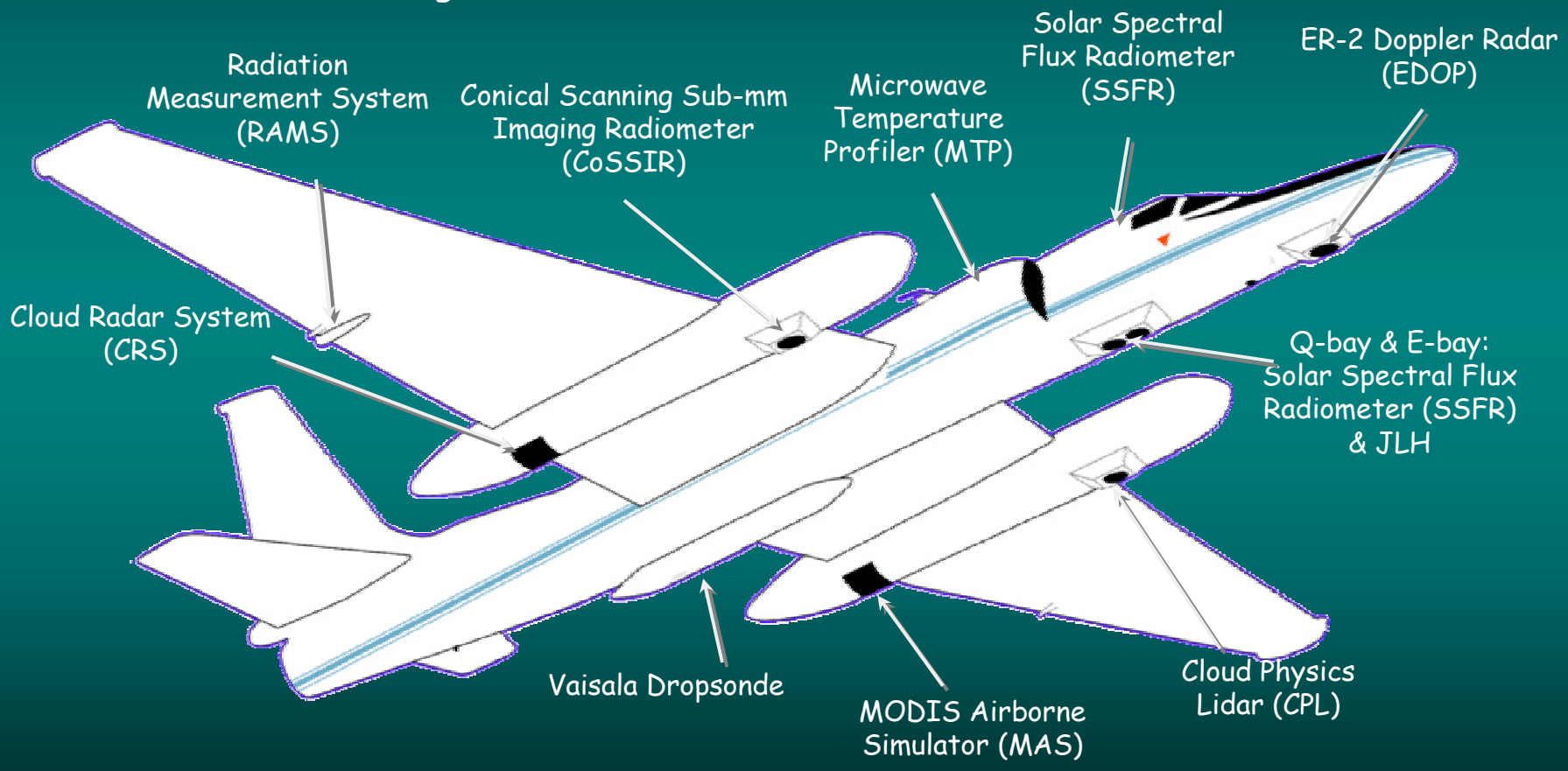
Remote Sensing of the Radiative and Microphysical Properties of Cirrus Clouds during CRYSTAL-FACE with the MODIS Airborne Simulator

Steve Platnick and Michael King

- Participate in flight planning of the NASA ER-2 aircraft over subtropical cirrus clouds in southern Florida during the July 2002 field campaign
- Build a well-calibrated and feature-rich data set to validate the MODIS cloud products (including mask, cloud thermodynamic phase, cloud top properties, optical thickness, and particle size), making use of the increased spectral and spatial information available from MAS
- Retrieve cirrus cloud properties over Florida and surrounding Gulf of Mexico waters using MAS
- Work with other CRYSTAL-FACE instrument teams on synergistic science efforts

NASA ER-2 Aircraft

CRYSTAL-FACE Configuration



MODIS Airborne Simulator

- Platform
  - ER-2
- Altitude
  - 20 km (nominal)
- Sensor Characteristics
  - 50 spectral bands ranging from 0.47 to 14.3 μm
  - scan ±43°
  - instantaneous field of view 2.5 mrad
  - scan rate 6.25 Hz
  - 16 bits per channel
  - 1.72 GB hr^{-1}
  - 716 pixels in scan line
  - calibration
    - » integrating sphere on ground
    - » two on-board temperature controlled blackbodies